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# AUTOMATIC VENTILATION OF COMMON STORAGES

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## INTRODUCTION

The extent to which common storage is used is often not appreciated, partially because there are no reliable statistics which describe the contents or even the number of such storages. There is also some tendency to consider common storage as a crude arrangement for the preservation of fruits, vegetables and nursery stock. Familiarity with the storage method makes possible some general statements concerning its nature, its importance, its weaknesses and the possibility of improving its performance.

A common storage differs from a refrigerated storage only in the method used to establish a desirable temperature for the storage of any given commodity. The common storage depends to some extent on soil temperatures (if underground) but largely on ventilation with outside air for the maintenance of desired temperatures. Since summer temperatures are generally too high to exert a marked preservative effect, only fall harvested crops are placed in common storage.

The present importance of common storages in Canada is indicated by the fact that most of the winter supplies of potatoes, turnips, onions, beets, parsnips, cabbage, and carrots, together with considerable quantities of apples, are held in common storage. There are several thousand commercial growers of vegetables in Ontario alone, and probably most of them have some form of common storage. This type of storage is used extensively by growers of horticultural nursery stock. There is a tendency on the part of turnip waxers and potato growers to build large, centralized common storage structures, some of them supported by government subsidies. Thus the utilization of common storage does not appear to be lessening.

The obvious weakness of common storage is its dependence on natural temperatures. However, in the opinion of the authors, inefficient operation, resulting in inaccurate temperature control, is a highly important weakness during the normal operating season. Any improvement in common storage must be applicable to many hundreds of storages if the improvement is to result in a *general* effect on the stored fall crops.

Despite the general use of common storage the authors were not able to find a report covering adequately the potential performance of common storages and in particular no record is at hand to show performance under automatic controls.

For purposes of this paper, good performance means that full use is made of cool outside air and that the desired temperature is maintained accurately. The present report has as its objective a study of performance,

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in terms of storage temperature, in two storages of commercial size which are situated on the campus of the Ontario Agricultural College, Guelph, Ontario.

Several years of manual operation of the ventilation systems showed the need of automatic controls before a detailed study could be attempted. Then it was found necessary to develop a suitable differential thermostat as part of the ventilation system.

This report contains first, a general description of the ventilation system used here and a full description of the new thermostat, and second, an analysis of performance based on temperature data collected during 18 months, and an estimate of probable performance during the past 20 years.

## AUTOMATIC VENTILATION SYSTEM

There are several possible methods of controlling ventilation. That which has performed well here is illustrated in diagrammatic form in Figure 1. Cool air is drawn through a duct past an automatic shutter to a space under a false, slatted floor. Warmer air is drawn from the room at a ceiling level by a fan and expelled past an automatic shutter in a duct leading to a short chimney. The fan is started by a differential thermostat when the outside air is slightly cooler than that inside. Ventilation proceeds until the outside and inside temperatures are nearly equalized or until a desired inside temperature is reached. In the former instance the differential thermostat breaks circuit and in the latter a cut-out thermostat operates. Air moves from floor to ceiling past the load and acquires heat which is delivered outside the building.

Auxiliary instruments include a small constant duty fan which circulates air in the storage to reduce the spatial differences in temperature associated with air stratification during periods of no ventilation. Connected with the air circulation system is a thermostat which controls a heat source for use in those storages where heat is known to be necessary.

All thermostats are sensitive enough that possible control of temperature is of the order of $\pm$ 1° F.

## NEW DIFFERENTIAL THERMOSTAT

All the parts of the ventilation system are standard but we were unable to find a differential thermostat which met our requirements. The latter are: first, sensitivity to a temperature difference of approximately 1° F. or better; and second, that the instrument must not be permanently distorted when the outside sensitive element is exposed to a seasonal temperature range of from 105° F. to $-$ 40° F.

Three variations of a thermostat were tested, and although two of them are not perfected, they have inherent qualities which warrant their description. The third one performs well and is now being manufactured.

The three thermostats have in common two air containing systems consisting of two copper wafers, each connected by copper capilliary tubing to a steel bulb. The systems are nearly equal in internal volume and a seal is made when the systems are at a temperature of about 25° F. (thus they are under positive pressure at the working range above 30° F.). One

bulb is affected by inside temperatures while the other is carried outside the storage. The latter is protected from direct sun radiation. The wafers are mounted in a rigid box with their inner faces joined by a rigid halter (in two types) so that motion of one wafer is transmitted to the other. In the remaining type, motion of the bellows is independent.

Type one is shown in Figure 2. A microswitch is pivoted on a wall of the box in such a manner that its final position is controlled by a screw and spring operating a lever arm extending from the microswitch. The microswitch is mounted within the halter but not in contact with it, except when its switch is depressed by motion of the halter in the direction of the wafer controlled by outside temperature. The microswitches used will carry 10 amperes at 110 volts, and thus directly control a fan motor of $\frac{1}{4}$ h.p., or a relay if more power is required. The first two models of type one were used successfully in our storages and they have the very considerable advantage of simplicity and ruggedness. The present difficulty came to light when duplicates were made. It was found that the wafers, as purchased, varied considerably in sensitivity and that the pressures necessary to operate the microswitches also varied. Sensitivity of some instruments was not better than 8° F. More uniform wafers (or bellows) and microswitches would erase the difficulty and make type one most desirable for common storage application.

Type two is shown in Figure 3. In it the wafers operate independently with one of them carrying an arm terminated by a carbon contact which completes circuit by pressure on a second carbon contact on the second wafer. Potentially, type two should be extremely sensitive but the models so far are affected by mechanical vibration. The electrical system in type 2 is similar to that in type 3.

Type three (Figure 4) is now in production. A rigid insulating rod extends through the halter and carries a carbon contact at its distal end. Circuit is made through a second carbon contact which is screw adjusted. Current is supplied from a transformer at 6.3 volts and circuit is completed through a few turns of heating wire wound about, but insulated from, a bent strip of aluminum metal. Heating increases the curvature of the aluminum metal and the resulting mechanical pressure positively operates the microswitch.

All three types are adjusted by placing both air bulbs in a container of cold water. When both bulbs are at the same temperature, the contacts are adjusted so that circuit is barely broken.

## PERFORMANCE

### *The Storages*

Both of the storages from which the data were obtained have dimensions approximately as follows: length, 20 feet; width, 20 feet; average height, 10 feet. They have flat roofs which slope from 11 feet at the front to 9 feet at the rear. Insulation is fill-type, 6 inches thick on walls and roof. Its theoretical insulating effect is similar to 4 inches of standard insulation. The latter thickness is used commonly when the storage temperature is between 32° F. and 40° F. The insulation was examined mid-way in the study and it was in satisfactory condition. The floors are not insulated.

EXPLANATION OF FIGURES 1 TO 5 (see opposite page)

FIGURE 1. Diagrammatic vertical section of a common storage. The arrows indicate direction of air flow.

A—Air inlet duct fitted with an automatic shutter and a manual door.
B—Load.
C—False, slatted floor.
D—Air circulation duct fitted with a fan and if necessary with a heater coil.
E—Heat control thermostat.
F—Cut-out thermostat in circuit with the ventilation fan.
G—Differential thermostat.
H—Air exit duct with fan, automatic shutter and manual door.
K—Sun shade over exterior sensitive element of the differential thermostat.

FIGURE 2. Differential thermostat, type 1. Copper wafers, A, are 3 inches in diameter, connected by $\frac{1}{8}$ inch O.D. (or smaller) copper capillary tubing C, to air-bulbs, B, length of B, 7 inches, diameter 2 inches, steel tubing. Halter G connects the inner faces of wafers A. Top and lateral view of micro-switch D pivoted at E and position-adjusted at H. Movement of the halter G to the right makes circuit in the micro-switch.

FIGURE 3. Differential thermostat, type 2. Wafers A, tubing C, and air bulbs (not shown) are identical with those in type 1. Motion of wafers A is transmitted to two carbon contacts P, the upper contact is adjustable by screw H. Wafer A, left, is connected to the outside air bulb. A small electric current passes through points P with auxiliary arrangements identical to those in Figures 4 and 5.

FIGURE 4. Differential thermostat, type 3. Wafers A, air bulbs B, capillary tubing C and halter G are identical to those in type 1. A rigid plastic rod J is fastened to the halter G. Rod J carries a carbon contact P at its lower end. It completes circuit through a second carbon contact P which is adjustable by screw H. Its electrical circuit includes a transformer K, heating wire N, coiled about a bent aluminum strip M. Curvature of the aluminum strip is adjustable by screw H. The convex equator of the aluminum strip is in contact with the switch button of a micro-switch D. Strip M expands with heat when contacts P come together. Expansion of strip M operates the micro-switch.

FIGURE 5. Schematic wiring diagram for differential thermostats types 2 and 3 and their accessories. $T^1$ is an integral cut-out thermostat operated by room temperature. $T^2$ is the differential thermostat carrying a 6.3 volt current (0.5 amp.) from a transformer. The bent aluminum strip is shown in contact with the micro-switch S which operates the load L either directly or through a relay.

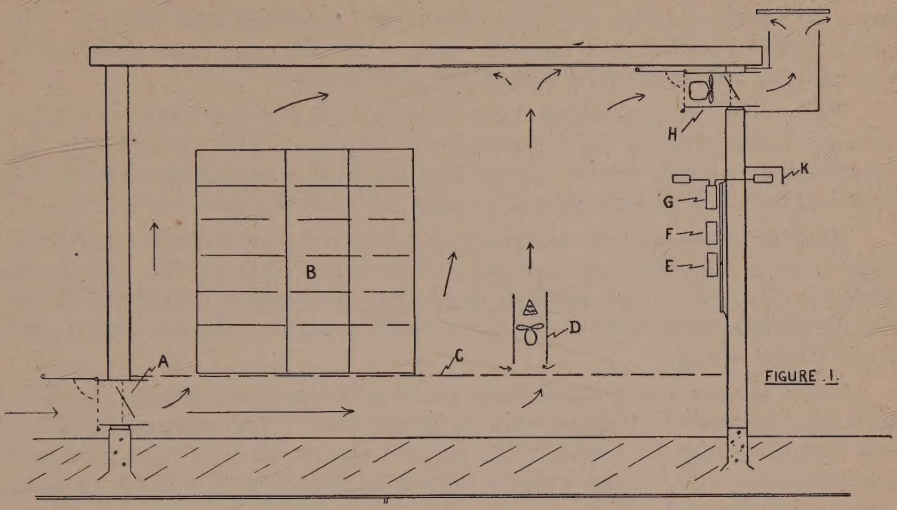
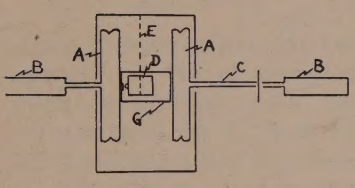



FIGURE 1.



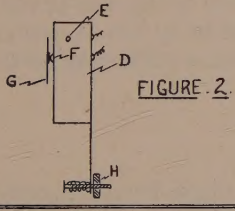




FIGURE 2.

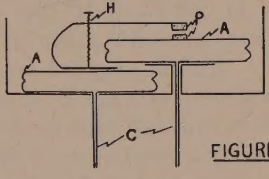



FIGURE 3.

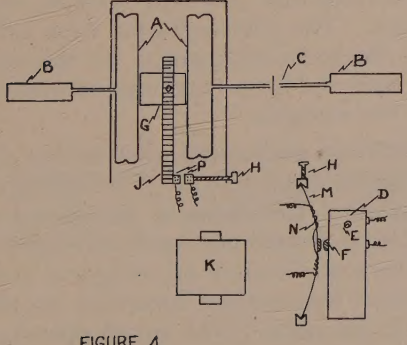



FIGURE 4.

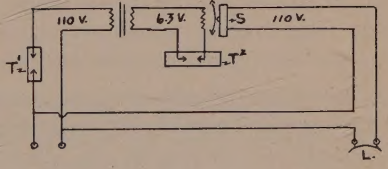



FIGURE 5.

FIGURES 1-5. (For explanation see opposite page)

One of the storages is of frame construction with heavy asphalted paper and $\frac{1}{2}$ inch lumber on both sides of the studdings and rafters. The roof is finished with heavy roofing paper. The sill rests upon cedar piles. This storage will be referred to as the frame storage.

The second storage has an outer bearing wall, 8 inches thick, of cinder-concrete blocks resting on a concrete foundation. The finish inside the insulation is painted, $\frac{1}{2}$-inch lumber and the roof is similar to that on the frame storage. This storage will be referred to as the concrete storage.

Both storages may be described as adequate, cool storage structures. They have a high ratio of exposed surface area (1200 sq. ft.) to volume (4000 cu. ft.). They are isolated from other structures, but the concrete storage shades, from most of the sun's direct radiation, the southwest wall of the frame storage.

Other factors being equal, heat gains and losses are greater, proportionately, in smaller storages than in larger ones. The storages here are near minimum size for commercial use and the problem of heat gain and loss associated with surface-volume ratio is as serious as it is likely to be in commercial storages.

*Required Storage Temperatures*

The lowest temperature used in the commercial cool storage of horticultural materials is 30° F., but the most common is 32° F. Turnip, cabbage, carrot, beet, parsnip, onion, celery and many varieties of apples are stored at 32° F. Potato requires from 38° F. to 40° F. for long storage. The objective in common storage is to attain and hold those temperatures as soon as possible in the fall and to maintain them as late as possible in the spring. Obviously a temperature of 40° F. can be attained earlier and held later than a temperature of 32° F. The present work is related largely to the problem of reaching and holding 32° F.

*Recorded Temperatures*

The experimental data consist of the records made by a thermograph in each of the two storages. Each thermograph recorded outside and inside air temperatures on a 7-day chart. The thermographs were calibrated at the beginning of the study and checked subsequently by thermometers. On several occasions data were collected from maximum-minimum thermometers placed outside and inside the storages.

The measurements of temperature during mid-winter showed merely that the storages were being held at the desired temperature. The storages were empty, or nearly so, to allow maximum variations in temperature. During the winter of 1947-48 the ventilation system operated only briefly at isolated intervals of time. Because there was little or no biological heat produced in the storages the maintenance of temperature depended largely on a balancing of heat loss by an electric hot plate (1320 watts) operated by a thermostat.* The actual temperature was approximately 32° $\pm$ 1° F. in the winter season.

* Underground storages, held at 32° F., here require regular ventilation during winter to eliminate heat acquired from the soil.

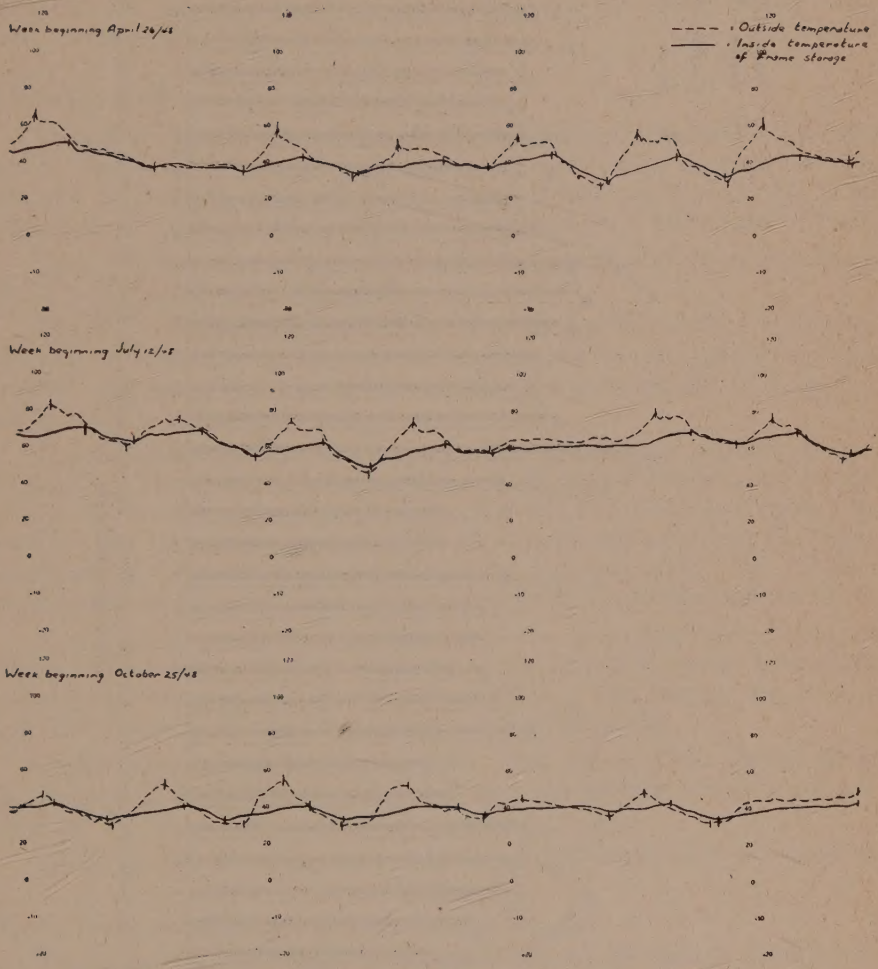



FIGURE 6. Temperature recordings, traced to synchronize time. Broken lines represent outside temperatures, continuous lines represent temperatures in the frame storage. Note that the inside temperature parallels the outside nightly drop in temperature. Vertical lines on the graphs represent principal trends as used in calculating time-temperature units.

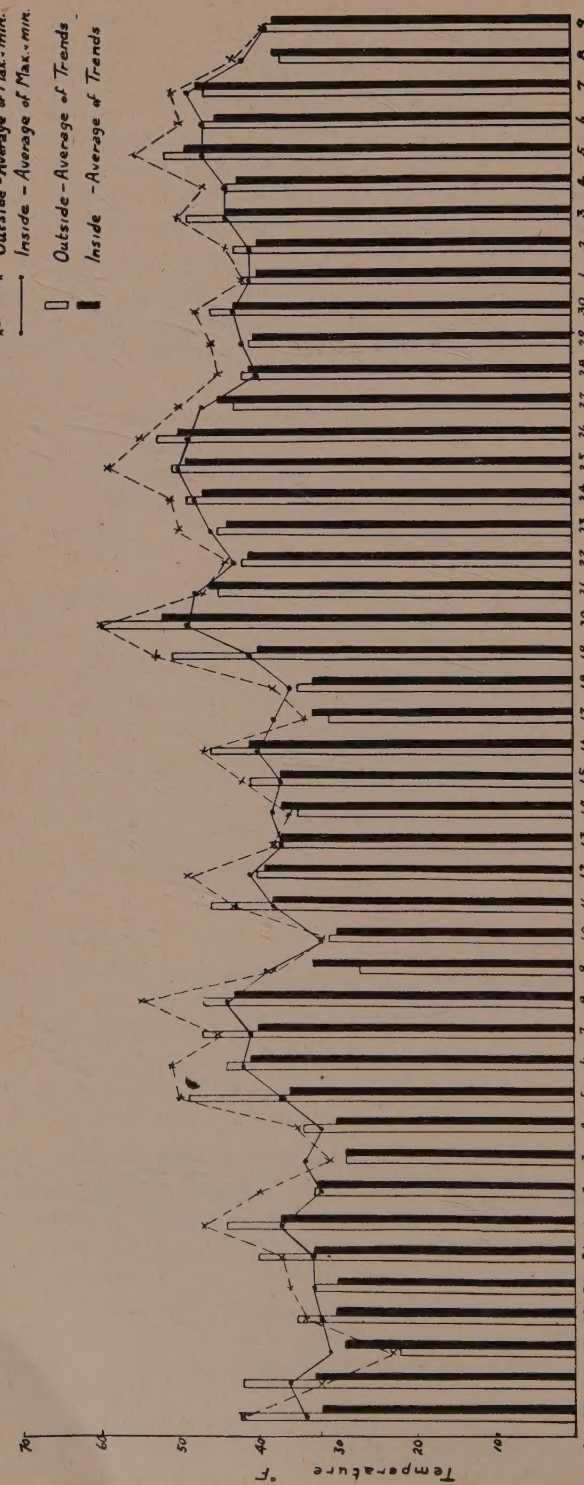



FIGURE 7. Daily averages of outside and inside temperatures as lines. Bars represent averages of temperature trends as shown on thermograph charts.

The season used for study began with the last week of adequately controlled storage temperature in the spring and ended when 32° F. was held steadily in the fall.

Tracings of thermograph charts (Figure 6) are typical of records obtained in the spring, summer, and fall seasons. Publication of all the charts would not only consume too much space but would not provide easily interpreted information.

*Maximum-Minimum Temperature Averages*

During the season selected for study, the temperatures both inside and outside the storages were fluctuating and it is therefore necessary to use averages to describe the conditions. One method used commonly is to average the maximum and minimum temperature for a given unit of time.

That method was adopted to study daily temperature relationships over a period of 45 days (Figure 7).

The daily average maximum-minimum outside is shown as a broken line and a solid line represents the corresponding averages inside the concrete storage. The average condition is approximately 6° F. higher temperature outside than inside.

A somewhat more accurate comparison of average temperatures is obtained by averaging the temperatures of the major temperature trends as seen on thermograph records. Such averages are shown in Figure 7 by vertical clear bars representing outside conditions and solid bars for inside temperatures. The average condition is approximately 3° F. higher temperature outside than inside with a range of daily difference up to 12° F.

It should be noted that the electric heater was disconnected prior to March 26 (when the records in Figure 7 began), but the cut-out thermostat was still operating to stop ventilation at 32° F. The storage was empty. Any drift below 32° F. was due to uncontrolled heat loss.

Inside temperatures were at or lower than 32° $\pm$ 1° F. during 13 of the 24 days to April 18. On all but 4 days the storage temperature was below 40° F.

After April 19 the storage temperature was ordinarily at or above 40° F.

*Weekly Averages of Trends*

Inside and outside temperature conditions for the season March 8 to December 6, 1948, are illustrated in Figure 8.

The broken line represents the maximum outside temperature for each week. The solid line represents the weekly average of outside daily average of maximum-minimum temperatures. Vertical bars represent average temperatures as determined by averaging the major trends on the thermograph charts. Clear bars, solid bars and cross-hatched bars illustrate, respectively, outside, concrete storage and frame storage temperatures.

Over the season in question the frame storage maintained a temperature averaging 6° F. lower (average trend temperatures) than the outside temperature as represented by averages of maximum-minimum temperatures.

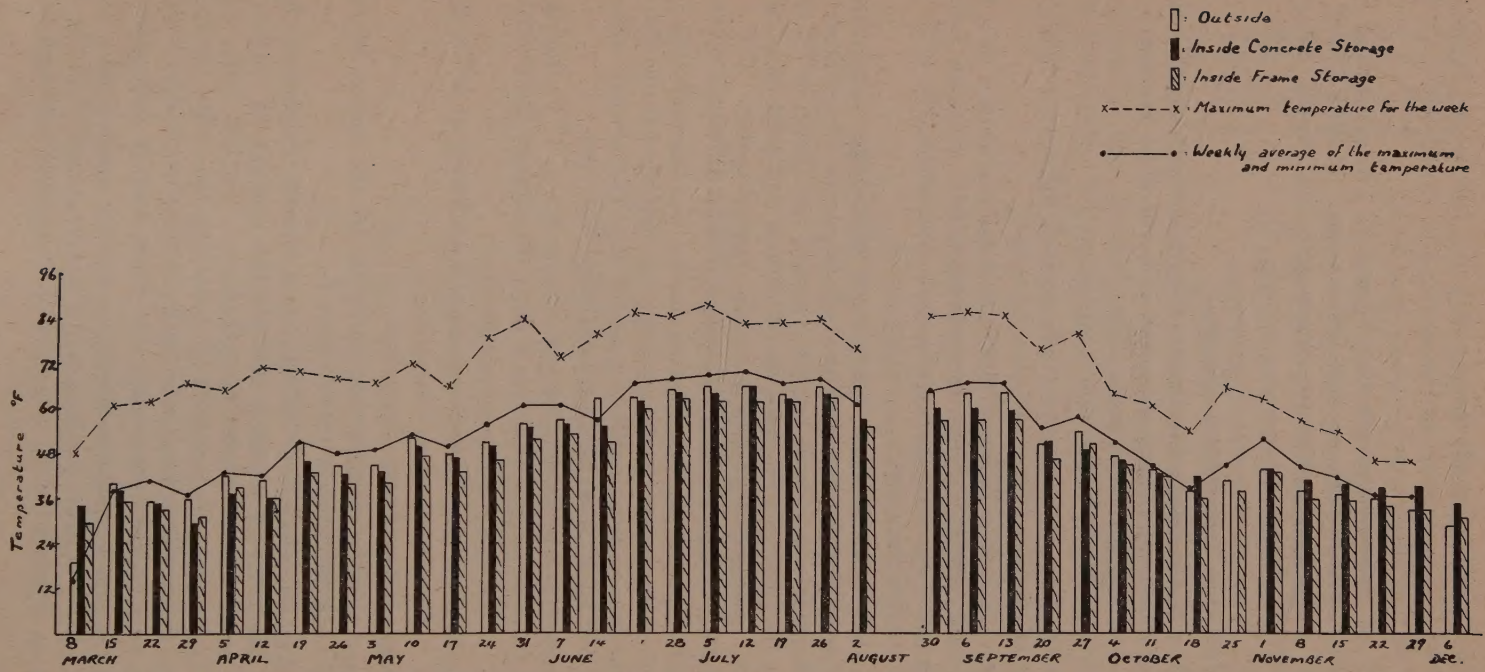



FIGURE 8. Weekly averages of outside daily maximum-minimum temperatures are shown as a solid line. A broken line represents maximum outside temperature for each week. Bars show averages of trends as seen in thermograph records.

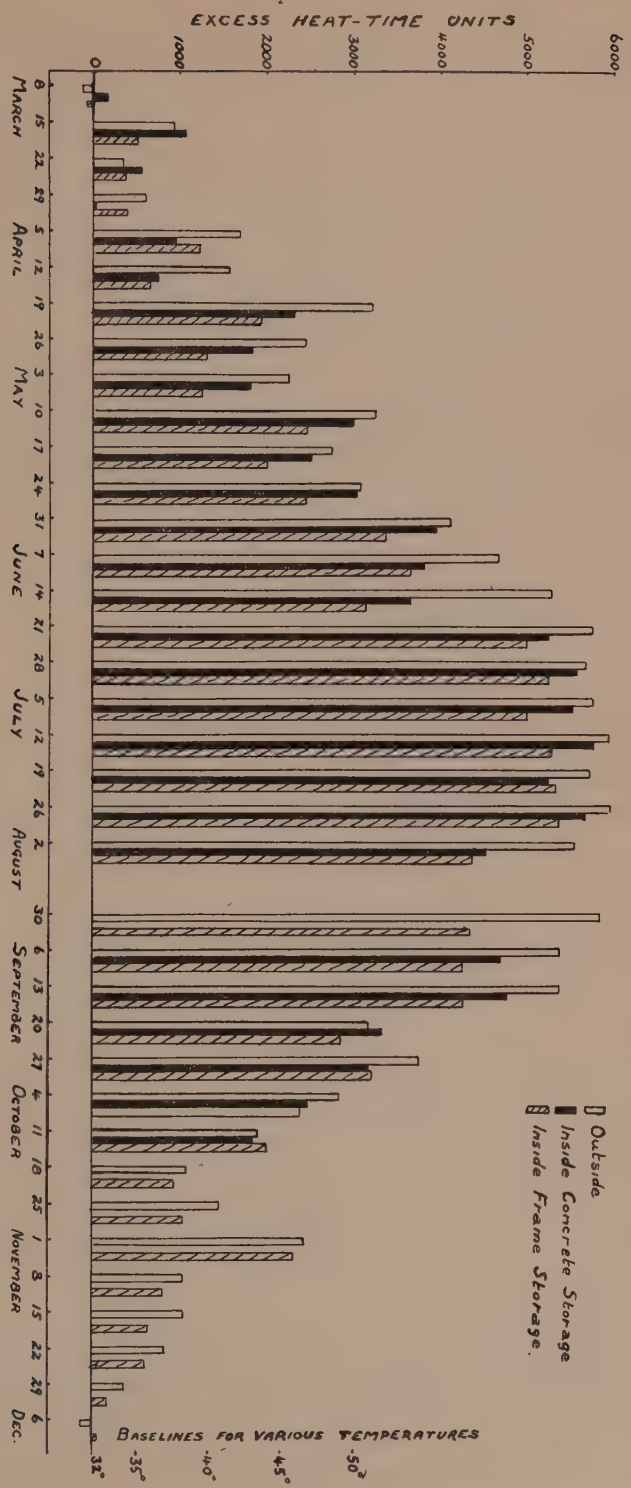



FIGURE 9. Heat-time unit comparisons of outside and inside conditions; 32° F was used as a base line.

*Heat-Time Unit Comparisons*

An accurate description of fluctuating temperatures takes into account both time and temperature. Each major temperature trend in the thermograph records was marked on each record. The average temperature of each trend was multiplied by the number of hours' duration of each trend. The sums obtained were totalled for each week to give a total of "heat-time" units for the week. If the storages were held constantly at 32° F. there would be only one storage trend with an average temperature of 32° F. maintained during the number of hours in a week. Subtraction of this sum from the heat-time units actually found provides a direct comparison of the relationship between inside and outside temperatures with duration of temperatures taken into account.

Such a comparison is made in Figure 9, where the weekly heat-time units in excess of those at 32° F. are shown as vertical bars. Clear, solid and cross-hatched bars represent respectively outside, concrete storage and frame storage conditions. Comparisons based on uniform temperatures higher than 32° F. can be made by drawing horizontal lines in the positions indicated on the right of Figure 9.

Appropriate horizontal lines show that the storages were above 50° F. from June 1 to October 4, above 40° F. from April 19 to October 18, and above 32° F. from March 8 to the end of November.

## DISCUSSION AND SUMMARY

Prior to the development of a sensitive, automatic system of ventilation for common storages it was difficult to estimate possible performance, in terms of sustained temperatures, in this type of storage. The ventilation equipment described here operates primarily under control of a differential thermostat. The design of the thermostat is described in detail. The ventilation system appears to result in nearly optimum use of naturally refrigerated air.

Common storages are in very general use and there are some indications that their use may be expanded. It is believed that the performance of most of the existing storages may be greatly improved by adequate control of ventilation.

Since natural air varies in temperature it is necessary to describe the temperature in terms of averages per unit of time. Three methods of describing average conditions are presented. Daily maximum-minimum averages both inside and outside a storage are compared (Figure 7). Averaging the number of trends of temperatures shown in thermograph charts takes duration of temperature partially into account (Figures 7 and 8). Time-temperature units (Figure 9) emphasize duration of temperature. All three methods show that storage temperature averages lower than outside temperature.

Daily averages of maximum-minimum temperatures are obtainable from meteorological stations in most areas in Canada, whereas trend data may be more difficult to obtain and use. A comparison was made between the inside average of trend temperatures (on a weekly basis) and outside daily averages of maximum-minimum temperatures, averaged for each week, during March to December, 1948. The inside temperature averaged 6° F.

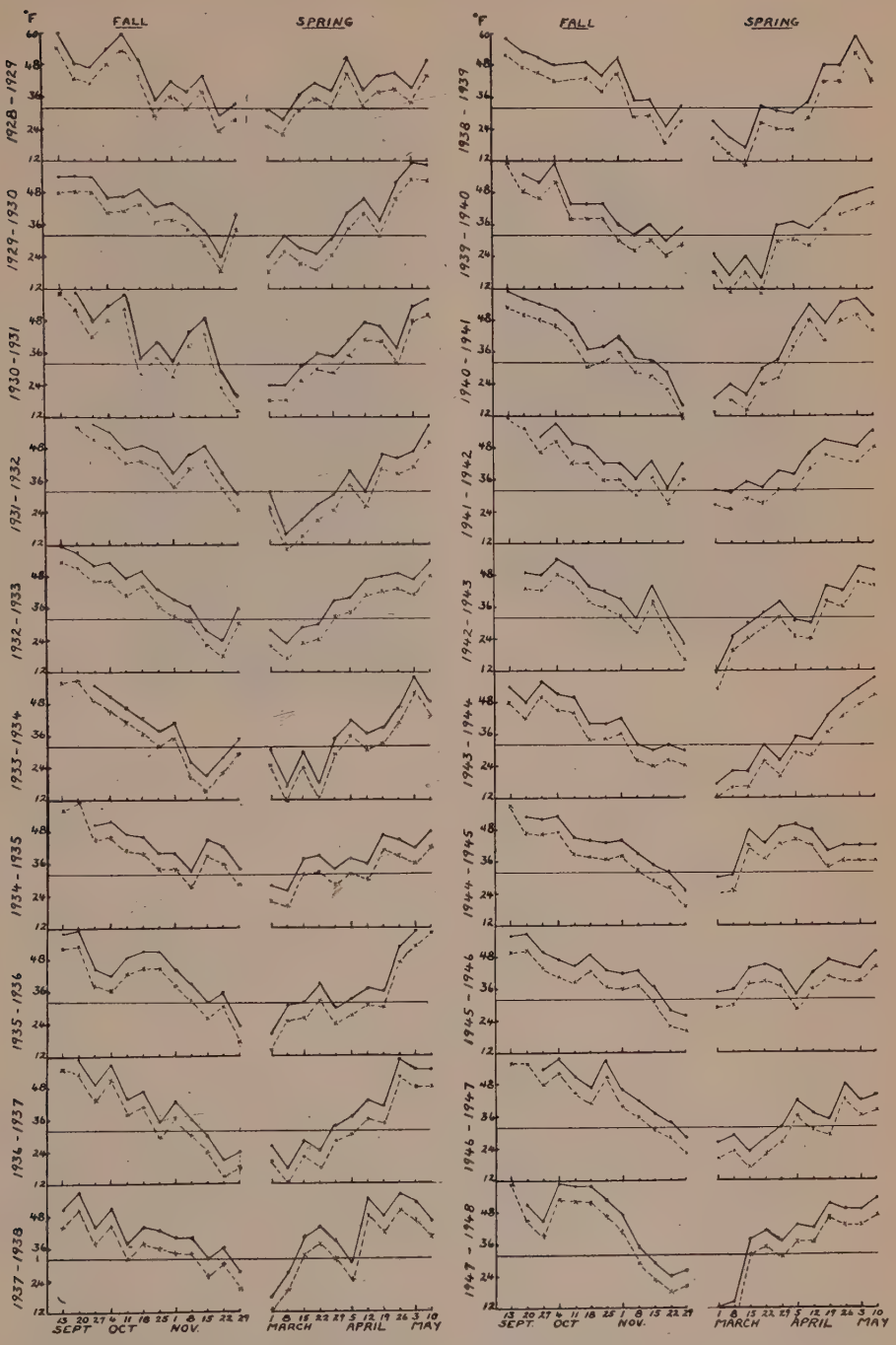



FIGURE 10. Outside weekly temperature averages for fall to spring storage terms, beginning 1928-29 and ending 1947-48. The broken line is the assumed storage temperature.

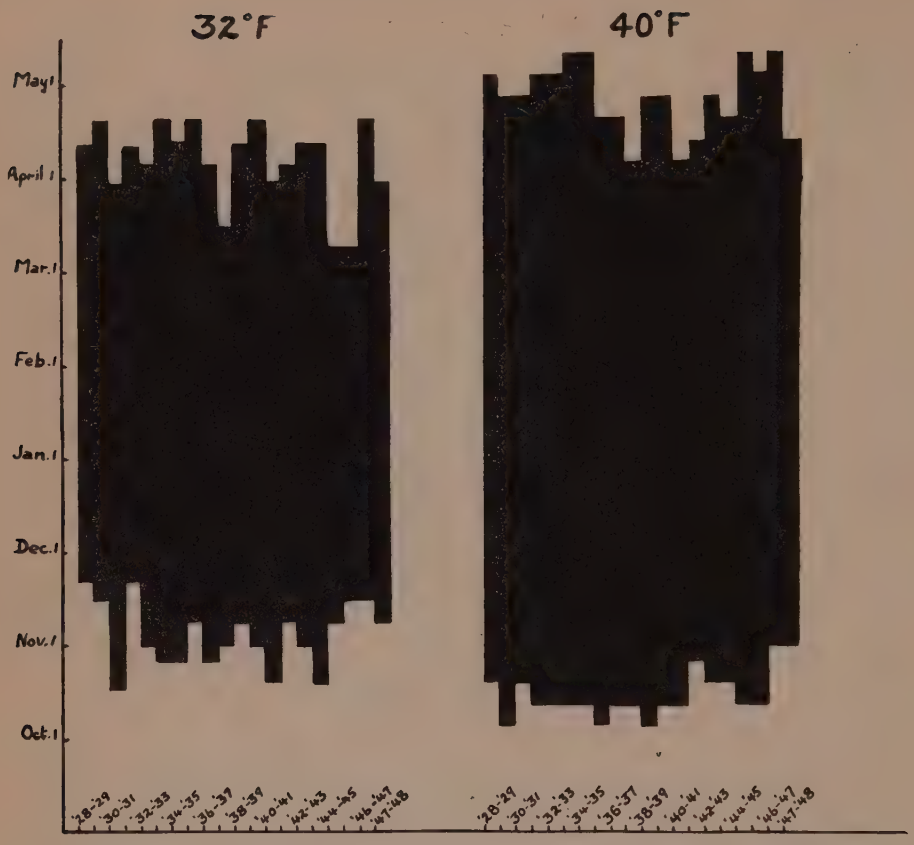



FIGURE 11. Charts showing estimated duration of storage temperatures of 32° F. and 40° F., respectively, over a 20-year period at Guelph.

below that outside during that period. It is now believed that an adequately insulated storage, with automatic ventilation, will perform, on the average, in such a manner that its temperature will be at least 6° F. below that represented by averages of outside maximum-minimum temperatures.

Outside average temperatures during the past 20 years here were plotted to show conditions during each fall and the following spring. The probable storage temperature was plotted 6° F. below outside averages (Figure 10). The probable duration, together with beginning and ending dates, for inside temperatures of 32° F. and 40° F. are charted in Figure 11. Averages of the 20-year, probable performance, are: 4.7 months at 32° F. with a range of 3.7 to 5.7 months; and 6.3 months at 40° F. with a range of 5.5 to 7 months.

Some estimates can be made of the possible performance of other adequately insulated above-ground storages.

Larger storages, if provided with relatively the same ventilation capacity, should perform similarly. Somewhat lower averages might be obtained in that the ratio of volume to exposure of walls and roof is more favourable in the larger storage.

The effect of loading in the fall is difficult to estimate in that the temperature of the incoming load will vary greatly and the method of packaging and stacking may limit the rate of cooling. However, if harvested materials are cooled overnight outside the storage it should be possible to obtain very little disturbance of the storage air temperature when the material is loaded in the morning. Load during winter and spring will serve to smooth inside temperatures and reduce the effectiveness of short periods of late spring low temperature air.

It is not possible to predict performance in storages subject to various sources of heat. Examples are storages at various depths underground, in heated cellars or in barns where one or more walls are subjected to barn temperatures.

The adoption of automatic controls for ventilation and of an auxiliary heat source (where necessary) has resulted in accurate winter control (approximately $\pm$ 1° F.) of temperature in an above-ground common storage. Estimates of performance during the past 20 years show that the principal weakness of the common storage is the variation in the date when 32° F. can be reached and maintained in the fall season. That date has varied between October 15 and December 1 during the past twenty years. The condition is, of course, ameliorated by the fact that temperatures somewhat above 32° F. have preservative effects. Early termination of the desired temperature in spring is less important in that much of the storage load has been consumed during the winter months.

The adoption of the automatic ventilation system has resulted here in much more efficient utilization of cool outside air than is a practical possibility with manual controls. Then since the thermostats are adjusted at factory according to the products stored, and since an adequate structure automatically adjusts itself to a temperature suited to the product, the grower is thereby presented with a convincing demonstration of the desirability of proper storage temperature, during the first year of operation. Reports to that effect have already been received from some of those who have used the system. Performance in the grower's storage seem to be a much more effective educational method than demonstrations in our experimental storages.

## ACKNOWLEDGMENTS

The authors acknowledge gratefully help received from the following sources: the Department of Physics, Ontario Agricultural College, in the collection of temperature data over a 20-year period; the W. C. Wood Company, Guelph, Ontario, for providing trial ventilation equipment according to our specifications; and A. H. Northcott, instrument maker, Guelph, Ontario, who gave invaluable assistance and advice in the development of the differential thermostat which is described herein.

# STUDY OF FERTILIZER UPTAKE USING RADIOACTIVE PHOSPHORUS

## IV. THE AVAILABILITY OF PHOSPHATE CARRIERS IN CALCAREOUS SOILS

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In Western Canada, 11-48-0 ammonium phosphate is the usual phosphate fertilizer, and fertilizer trials have indicated that this form is superior to ammoniated superphosphate, 2-20-0, or triple superphosphate 0-38-0, the latter forms being calcium phosphates (9). Ensminger and Cope (4) have recently reported on a comparison of these materials in Alabama, and conclude that ammonium phosphate is an inferior source of phosphate under their conditions. Several such comparisons between different phosphate carriers have been conducted (2, 8) but relatively little precise information is available for the calcareous soils of semi-arid, sub-humid regions.

Preliminary results previously reported (3) had indicated large differences in availability between different forms of phosphate, suggesting that under soil conditions of neutral to alkaline reaction, calcium phosphates are relatively inferior sources of phosphate for wheat. In order to obtain more information on this point, and to check the tentative greenhouse conclusions in the field, the experiments reported here were set out in the 1948 season. Radioactive phosphorus was used as a tracer to determine accurately the amounts of fertilizer phosphorus taken up.

Comparisons made in the field (9), indicating that 11-48-0 ammonium phosphate is superior to 0-38-0, a triple superphosphate, have raised the question whether the superiority of 11-48-0 ammonium phosphate has been due entirely to the value of its nitrogen as a nutrient. Dressings of ammonium sulphate have given no general yield increases in field tests (12). The experiments reported here were designed to answer this question by comparing equal rates of phosphate application, the carriers being: (1) mono-ammonium phosphate; (2) mono-sodium phosphate; (3) mono-calcium phosphate; (4) dicalcium phosphate, and (5) dicalcium phosphate plus calcium nitrate, which gives a slightly higher nitrogen addition than that of the ammonium salt. In addition, two other rates of ammonium phosphate application were included, as well as an unfertilized treatment, to give additional information on the influence of rate of application on fertilizer uptake (2, 11, 17).

### MATERIALS AND METHODS

#### *Preparation of Fertilizers*

The radioactive fertilizers were prepared by adding the radioactive phosphorus in the form of phosphoric acid to solutions from which the various phosphates were obtained by evaporation. In solution and in the crystallization process, the $P^{32}$ tracer would distribute itself at random with regard to $P^{31}$, and hence would indicate exactly the fate of the phosphate in the fertilizer applied to the soil.

[1] Associate Professor of Soils, Graduate Assistant in Soils, and Professor of Chemistry, respectively.

Radioactive mono-ammonium and mono-sodium phosphates were prepared by evaporation at less than 45° C. of solutions of the respective salts, to which $P^{32}$ as $H_3PO_4$ had been added. Crystal growth was controlled to some extent by the frequency of stirring during the evaporation.

The radioactive mono-calcium phosphate was prepared by dissolving mono-calcium phosphate and the radioactive phosphoric acid solution in water and recovering the material by evaporation as in the sodium and ammonium preparations. However, the lower solubility of the mono-calcium salt meant that very large quantities of solution would be required. This was avoided by incorporating the radioactivity, by solution and evaporation, into about one-quarter of the required amount of material, grinding to less than 100 mesh in an agate mortar, and mixing with similarly ground non-active material until tests for $P^{32}$ on representative samples showed homogeneity within the limits of counting error.

The radioactive dicalcium phosphate was prepared by adding the $P^{32}$ to the dicalcium phosphate dissolved in 25 per cent acetic acid. According to Larson (7), pure dicalcium phosphate is prepared by crystallization of about 5/6 of the dissolved material. To avoid the resulting delay in recovering the tracer lost, the preparations were evaporated to a thick paste, to recover as dicalcium phosphate all the tracer added. In this case also, the $P^{32}$ was incorporated into only a fraction of the desired quantity, the required amount being obtained by grinding and mixing until homogeneity was achieved, within the limits of error of the counting system.

The radioactive mixture of dicalcium phosphate and calcium nitrate was prepared by mixing the ground active dicalcium phosphate with ground calcium nitrate.

The phosphates, in a semi-liquid crystalline state, were pelleted by forcing the moist mass through a sieve of suitable mesh, allowing it to dry, sieving out the desired size fraction, and repelleting the finer fractions. This was done to simulate as closely as possible the coarse granular condition of the commercial products used on the Canadian prairies.

Precautions were taken to avoid radiation hazards from the $P^{32}$ and to avoid inhalation of radioactive dust.

*Plot Arrangement*

To give some factor of insurance against weather and other hazards, identical trials were laid down at Aberdeen on Elstow Clay, a chestnut soil on shallow glacial lacustrine material; at Humboldt on Naicam Loam, a chernozem on resorted glacial till, and at Birch Hills on Melfort Silty Clay Loam, a thick chernozem on deep glacial lacustrine deposits (10).

The design of the trials was a modified Latin square of 4 replicates and 4 harvest dates, to permit following fertilizer uptake throughout the growing season to harvest. Each block consisted of 8 treatments, as shown in Table 1, with full randomization within each block.

Each treatment plot consisted of 5 rows 9 feet long, 6 inches apart. The two outside rows were guard rows, and were fertilized uniformly with 11-48-0 commercial ammonium phosphate at a rate of phosphate equivalent to that of the treatment. The three inner rows were given the designated

fertilizer treatment, with only the middle row being fertilized with radioactive fertilizer. This arrangement was adopted so that analysis of the two rows adjacent to the tracer row would indicate how much of the fertilizer applied to the middle row was being taken up by the plants of the adjacent rows, and conversely, how much of the $P^{31}$ in the plants of the tracer row came from the fertilizer of adjacent rows. This potential source of error was controlled in this manner, and further, the method permitted an estimate of the degree to which one row of plants feeds on fertilizer in the root zone of another. A comparison of plant weight from the tracer rows and adjacent rows with the same fertilizer treatment also permitted an estimation of any effects of $P^{32}$ itself on the growth of the above-ground parts, to give further information on the dangers of injury reported by Scott-Russell and Martin (13). The centre 6 feet of the middle row was harvested for yield and for analysis. The four harvest dates were chosen to give plants approximately at the following stages of development:

I—shot-blade stage, III—soft-dough stage,
II—heading, IV—maturity.

The treatments, together with the amounts of nutrients supplied, and the concentration of $P^{32}$, are given in Table 1 below. A higher initial concentration of $P^{32}$ was necessary for those blocks going to maturity to allow for the decay factor.

TABLE 1.—FERTILIZER TREATMENTS

| Material | Nutrients supplied, lb./acre | | Activity of tracer fert. $\mu c/gP^{31}$* | |
|---|---|---|---|---|
| | $P_2O_5$ | N. | First 3 harvests | Fourth harvest |
| 1. Mono-ammonium phosphate; half rate | 12 | 2.8 | | |
| 2. Mono-ammonium phosphate; basic rate | 24 | 5.5 | | |
| 3. Mono-ammonium phosphate; double rate | 48 | 11 | 35 $\mu c$ | 360 $\mu c$ |
| 4. Mono-sodium phosphate | 24 | 0 | | |
| 5. Mono-calcium phosphate | 24 | 0 | | |
| 6. Dicalcium phosphate | 24 | 0 | | |
| 7. Dicalcium phosphate—calcium nitrate | 24 | 6.4 | | |
| 8. Unfertilized | 0 | 0 | | |

* As at May 12, 1948.

The plots were seeded late in May, 1948, with Thatcher wheat at $1\frac{1}{4}$ bushels per acre, by means of a Kemp V-belt rod-row seeder, the grain and fertilizer being sown together. The metal wind deflector on the seeder was replaced by one of plate glass, to give protection against radiation and to give visibility, while the seed and fertilizer were being distributed on the V-belt.

*Analytical Methods*

The plant material from the harvested 6-foot portion of the row was dried at 105° C. and weighed. For analysis, the material was finely ground and mixed in a mechanical shaker. Aliquots of suitable size for

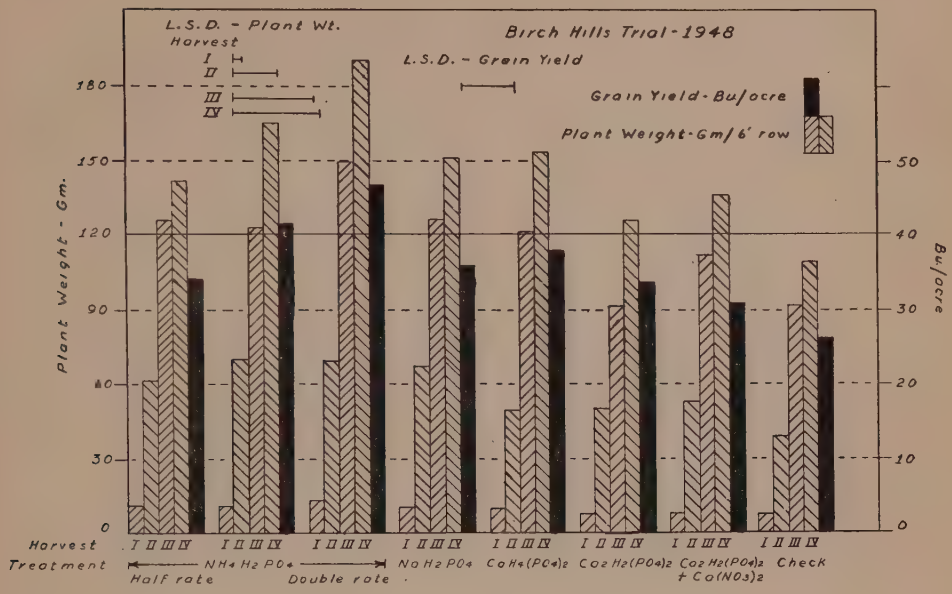


FIGURE 1

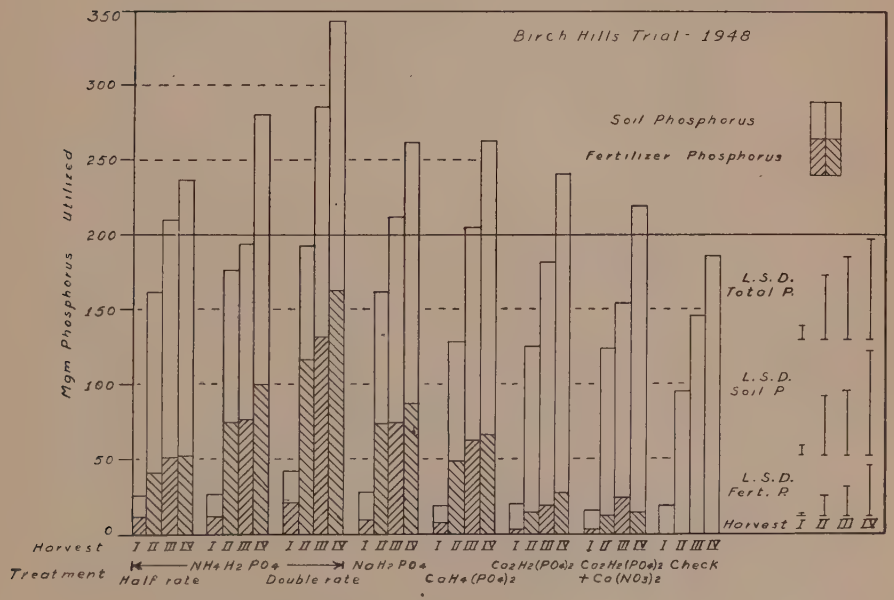


FIGURE 2

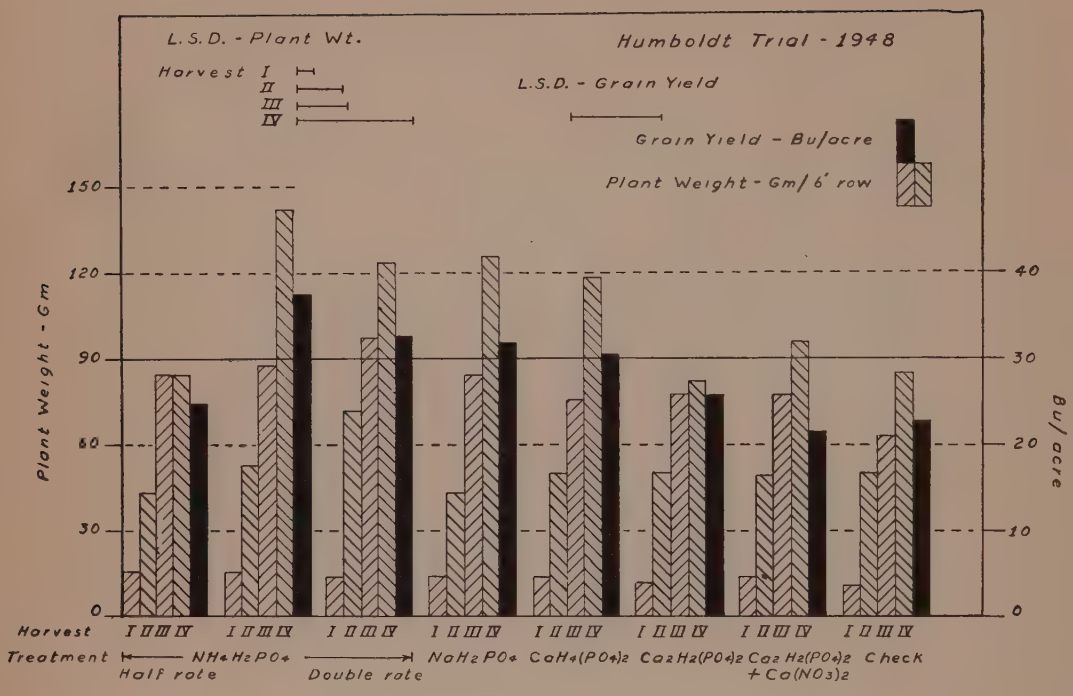


FIGURE 3

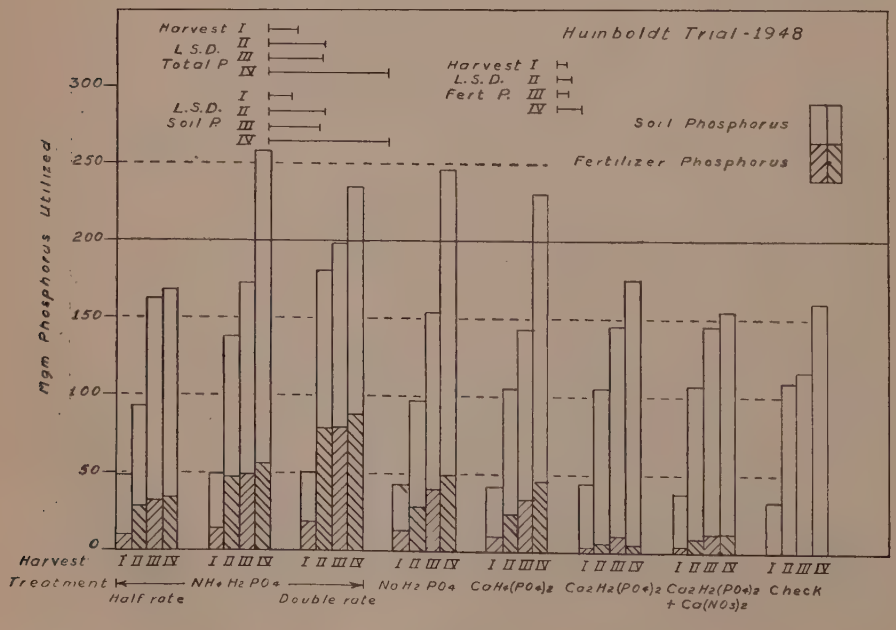


FIGURE 4

phosphorus analysis were wet ashed by the method of Brenner and Harris (1). After diluting to a known volume and filtering, portions of the solution were used for the estimation of total phosphorus by the colorimetric method suggested by Shelton and Harper (14), and for the estimation of $P^{32}$, according to previously described methods, involving the correction for self-absorption (15).

The sample taken at maturity was hand-threshed to obtain the weight of grain and straw. The grain and straw were then ground separately, and the phosphorus determinations carried out on a sample containing grain and straw material in the same proportion as determined at threshing.

## RESULTS

Some difficulty was experienced with germination, due to the very hot, dry spring, and at one location, Aberdeen, early growth was so slow and irregular that the trial was discarded, while at Birch Hills one block germinated so poorly as a result of a seeding accident that it was treated as a series of missing plots for the harvest affected.

In general, growing conditions were not good during the early part of the year due to high temperatures and lack of rain. The normal June rains appeared in July, however, and yields were good, although the season was late.

Large differences could be observed in the growth of the various plots, ammonium phosphate being outstanding. The dicalcium phosphate preparations were relatively ineffective, on a basis of visual estimates.

The above-ground portions were taken for determination of oven-dry weight and phosphorus and radiophosphorus content. The results are given in Table 2 (a), 2 (b), and Table 3. The numerical data of Table 2 are presented in simpler form in Figures 1, 2, 3, and 4, as histograms. The required differences for significance are included in Figures 1 to 4, using standard methods of statistical analysis (5).

Various observations may be made on different aspects of the experiment.

### *Rate of Application*

It is obvious that as the rate of application of ammonium phosphate was increased, the plants took up additional amounts of fertilizer phosphorus, but the proportion of the applied phosphate taken up decreased. The values in the last column of Table 2 (a) and (b) indicate a steady decrease in the percentage of the applied phosphate utilized by the plant, in comparing the half, standard and double rate of application of $NH_4H_2PO_4$. It is interesting to note that in the case of the double rate of $NH_4H_2PO_4$, the fertilizer phosphorus supplied very nearly half of the plant's total requirement for phosphate.

### *Availability of Different Carriers*

In comparing the availability of the different carriers, the data show some divergence between locations. In all cases, the dicalcium phosphate and dicalcium phosphate plus calcium nitrate were only slightly available, with the nitrate-phosphate preparation being consistently superior but not

TABLE 2 (a).—YIELD AND ANALYTICAL DATA, BIRCH HILLS, 1948

(Sown, May 26, 1948)

Averages of four replicates

| | | Mono-ammonium phosphate | | | Mono-sodium phosphate | Mono-calcium phosphate | Dicalcium phosphate | Dicalcium phosphate + $Ca(NO_3)_2$ | Un-fertilized | L.S.D. 5 per cent pt. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Half rate | Basic rate | Double rate | | | | | | |
| Plant weight gm./6-ft. row | I June 21 | 10.9* | 10.8* | 13.4* | 10.6* | 9.5* | 7.6* | 8.1* | 7.6* | 2.9 |
| | II July 7 | 62.4 | 70.2 | 69.4 | 67.3 | 49.6 | 50.3 | 52.8 | 38.6 | 17.5 |
| | III July 23 | 126.2 | 122.7 | 149.0 | 125.9 | 120.7 | 91.0 | 112.1 | 91.4 | 31.7 |
| | IV Aug. 24 | 142.9 | 165.0 | 189.9 | 150.5 | 153.4 | 125.8 | 136.2 | 108.5 | 34 5 |
| Grain yield—bu./acre | | 34.1 | 41.6 | 46.8 | 35.9 | 37.8 | 30.9 | 33.8 | 26.1 | 8.1 |
| Total P., mg./6-ft. row | I June 21 | 25.8* | 27.0* | 42.7* | 27.7* | 18.9* | 16.7* | 19.7* | 18.8* | 8.8 |
| | II July 7 | 162.3 | 177.2 | 194.0 | 161.5 | 128.9 | 124.2 | 126.1 | 95.0 | 44.3 |
| | III July 23 | 211.2 | 195.1 | 285.9 | 211.8 | 205.4 | 154.8 | 181.6 | 145.9 | 56.3 |
| | IV Aug. 24 | 236.3 | 280.7 | 343.4 | 261.9 | 262.3 | 219.5 | 240.7 | 188.3 | 67.7 |
| Fert. P. taken up mg./6-ft. row | I June 21 | 12.2* | 12.5* | 21.3* | 10.1* | 7.1* | 2.7* | 1.9* | — | 1.4 |
| | II July 7 | 41.4 | 75.5 | 117.2 | 74.4 | 49.3 | 12.6 | 15.1 | — | 13.6 |
| | III July 23 | 52.1 | 77.3 | 132.4 | 74.5 | 62.9 | 19.1 | 19.1 | — | 20.2 |
| | IV Aug. 24 | 52.8 | 100.7 | 163.6 | 87.5 | 66.4 | 13.8 | 21.9 | — | 34.3 |
| Soil P. taken up mg./6-ft. row | I June 21 | 13.8* | 14.5* | 21.4* | 17.6* | 11.8* | 14.0* | 17.8* | 18.8* | 7.1 |
| | II July 7 | 120.9 | 101.7 | 76.8 | 88.0 | 79.7 | 111.6 | 111.0 | 95.0 | 39.9 |
| | III July 23 | 159.0 | 117.3 | 153.5 | 139.3 | 142.5 | 135.8 | 160.3 | 145.9 | 43.3 |
| | IV Aug. 24 | 183.5 | 180.1 | 179.8 | 174.4 | 195.9 | 205.8 | 218.7 | 188.3 | 70.3 |
| Fert. P. taken up as per cent of Fert. P. applied | I June 21 | 7.5 | 3.8* | 3.3* | 4.1* | 2.2* | 2.8* | 0.6* | — | — |
| | II July 7 | 23.5 | 23.0 | 17.9 | 22.4 | 15.0 | 3.9 | 4.6 | — | — |
| | III July 23 | 31.7 | 23.6 | 20.2 | 22.7 | 19.2 | 5.8 | 5.8 | — | — |
| | IV Aug. 24 | 32.2 | 30.7 | 25.0 | 26.7 | 20.3 | 4.2 | 6.7 | — | — |

* One replicate calculated as a missing plot.

TABLE 2 (b).—YIELD AND ANALYTICAL DATA, HUMBOLDT, 1948

(Sown, May 19, 1948)

Averages of four replicates

| | | | Mono-ammonium phosphate | | | Mono-sodium phosphate | Mono-calcium phosphate | Dicalcium phosphate | Dicalcium phosphate + $Ca(NO_3)_2$ | Un-fertilized | L.S.D. 5 per cent pt. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Half rate | Basic rate | Double rate | | | | | | |
| Plant weight, gm./6-ft. row | I | June 21 | 15.0 | 15.6 | 13.7 | 14.1 | 13.7 | 11.8 | 13.6 | 10.4 | 5.9 |
| | II | July 8 | 43.1 | 53.5 | 72.1 | 42.9 | 50.8 | 49.4 | 49.1 | 49.7 | 16.0 |
| | III | July 23 | 84.7 | 87.7 | 97.5 | 84.0 | 75.3 | 77.7 | 77.5 | 62.9 | 18.5 |
| | IV | Aug. 19 | 84.4 | 141.6 | 123.2 | 125.7 | 117.8 | 81.5 | 95.9 | 84.6* | 40.7 |
| Grain yield—bu./acre | | | 24.8 | 37.7 | 32.7 | 31.9 | 30.5 | 25.8 | 21.3 | 22.7* | 10.5 |
| Total P., mg./6-ft. row | I | June 21 | 48.9 | 49.7 | 50.9 | 43.5 | 42.5 | 38.6 | 44.7 | 33.3 | 19.0 |
| | II | July 8 | 92.9 | 138.5 | 181.7 | 97.3 | 105.9 | 107.4 | 106.1 | 109.7 | 37.0 |
| | III | July 23 | 163.1 | 172.8 | 199.7 | 154.2 | 143.5 | 146.3 | 146.0 | 116.5 | 35.6 |
| | IV | Aug. 19 | 168.9 | 258.5 | 236.9 | 247.2 | 230.7 | 155.5 | 174.4 | 160.7* | 78.0 |
| Fert. P. taken up mg./6-ft. row | I | June 21 | 10.6 | 14.6 | 19.4 | 12.3 | 10.1 | 2.6 | 3.7 | — | 6.3 |
| | II | July 8 | 28.1 | 47.5 | 80.4 | 28.2 | 24.6 | 4.9 | 7.8 | — | 9.0 |
| | III | July 23 | 32.2 | 48.8 | 80.7 | 40.7 | 34.1 | 10.1 | 10.7 | — | 7.7 |
| | IV | Aug. 19 | 34.7 | 56.8 | 88.8 | 49.5 | 46.3 | 4.8 | 11.7 | — | 15.9 |
| Soil P. taken up mg./6-ft. row | I | June 21 | 38.3 | 35.1 | 31.5 | 31.2 | 32.4 | 35.9 | 41.0 | 33.3 | 15.8 |
| | II | July 8 | 64.8 | 91.2 | 101.3 | 69.1 | 81.3 | 102.6 | 98.3 | 109.7 | 37.0 |
| | III | July 23 | 130.9 | 123.9 | 119.0 | 113.5 | 109.5 | 136.1 | 135.3 | 116.5 | 33.5 |
| | IV | Aug. 19 | 134.1 | 201.7 | 148.2 | 197.7 | 184.3 | 150.8 | 162.7 | 160.7* | 78.5 |
| Fert. P. taken up as per cent of Fert. P. applied | I | June 21 | 6.5 | 4.5 | 3.0 | 3.8 | 3.1 | 0.8 | 1.1 | — | — |
| | II | July 8 | 17.1 | 14.4 | 12.3 | 8.6 | 7.5 | 1.8 | 2.4 | — | — |
| | III | July 23 | 19.7 | 14.9 | 12.4 | 12.4 | 10.4 | 3.1 | 3.3 | — | — |
| | IV | Aug. 19 | 21.2 | 17.4 | 13.6 | 15.1 | 14.2 | 1.5 | 3.6 | — | — |

* Figures for two plots calculated as missing plots.

significantly so. The more soluble materials consistently rank themselves (from most available to least) as ammonium, sodium, and mono-calcium phosphate. For the later stages of growth, there are no significant differences between ammonium and sodium phosphates, and no significant differences between sodium and mono-calcium phosphates at any one location. At both locations, mono-calcium phosphate is significantly less available than ammonium phosphate, and significantly more available than either dicalcium phosphate or the dicalcium phosphate-calcium nitrate material.

A comparison of average fertilizer uptake in Table 3 at the two locations for the last harvest for the various carriers indicates the same situation as in the individual cases, with ammonium phosphate being significantly better than either sodium phosphate or mono-calcium, but the differences between sodium and mono-calcium phosphate being too small to be statistically significant on this test. The dicalcium phosphate preparations are markedly less available than the more soluble forms.

The nitrogen content of the material does not greatly change the amount of phosphate the plant recovers, although the indications are that the $Ca_2H_2(PO_4)_2 - Ca(NO_3)_2$ preparation is slightly better than $Ca_2H_2(PO_4)_2$, and that $NH_4H_2PO_4$ is slightly better than $NaH_2PO_4$, suggesting a small beneficial effect from nitrogen on phosphate uptake from fertilizers. However, comparing these four materials on the basis of presence or absence of nitrogen gives no statistically significant effect of nitrogen on phosphate uptake under the conditions of this experiment.

The relative values of the carriers tested here are quite different from those obtained by Ensminger and Cope (4). The different behaviour of the various materials in Alabama and in Saskatchewan is not surprising, since soil conditions are diametrically opposite, being humid and acid, and semi-arid and alkaline, respectively.

In semi-arid soils, reactions of pH 7.0 and above are the rule, with plentiful supplies of calcium. Under these circumstances, precipitation of phosphate as $Ca_3(PO_4)_2$, or precipitation and adsorption of phosphate ions on the surface of calcium carbonate particles is to be expected. The extreme importance of calcium in these reactions makes it appear that the most effective fertilizer would be one with a small tendency to conversion to $Ca_3(PO_4)_2$, and consequently one with no calcium, and that effectiveness could be expected to decrease as the calcium content of the material increases. In general, then, the greater the difference of the material from tri-calcium phosphate, the greater is its effectiveness, and conversely, the more nearly its form approaches tri-calcium phosphate, the faster will it be changed to difficultly available tri-calcium phosphate, and therefore the lower will be its effectiveness.

This demonstration of a big difference in availability of phosphate in various carriers has broad implications. We can say that the superiority of ammonium phosphate over calcium phosphates, as a fertilizer under neutral to alkaline soil conditions, is primarily because it remains available longer rather than because of the marked nutritional benefits of the nitrogen contained in the ammonium phosphate. On the brown and chestnut soils, where there is no general nitrogen deficiency that can be corrected with

TABLE 3.—SUMMARY OF DATA AT MATURITY, HUMBOLDT AND BIRCH HILLS COMBINED, 1948

| | Mono-ammonium phosphate | | | Mono-sodium phosphate | Mono-calcium phosphate | Dicalcium phosphate | Dicalcium phosphate + $Ca(NO_3)_2$ | Un-fertilized | L.S.D. 5 per cent pt. |
|---|---|---|---|---|---|---|---|---|---|
| | Half rate | Basic rate | Double rate | | | | | | |
| Fert. P. mg./6-ft. row | 43.7 | 78.8 | 126.1 | 68.5 | 56.4 | 9.2 | 16.8 | — | 17.8 |
| Soil P. mg./6-ft. row | 158.8 | 190.8 | 164.0 | 186.1 | 190.1 | 178.3 | 190.7 | 174.5 | 51.8 |
| Total P. mg./6-ft. row | 202.3 | 269.6 | 290.1 | 254.5 | 246.5 | 187.5 | 207.5 | 174.5 | 50.1 |
| Plant weight, gm./6-ft. row | 113.7 | 153.3 | 156.6 | 138.1 | 135.6 | 103.6 | 116.0 | 96.5 | 26.6 |
| Grain yield, bu./acre | 30.5 | 41.2 | 41.3 | 35.2 | 35.4 | 27.1 | 30.8 | 25.3 | 7.25 |

TABLE 4.—FERTILIZER TAKEN UP FROM THE ACTIVE ROWS BY ADJACENT ROWS

(Expressed as percentage of applied phosphate)

| Location and harvest | | | Ammonium phosphate, half rate | Ammonium phosphate, basic rate | Ammonium phosphate, double rate | Sodium phosphate | Mono-calcium phosphate | Dicalcium phosphate | Dicalcium phosphate + $Ca(NO_3)_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Birch Hills | I | June 21 | 0.08 | <0.01 | <0.04 | <0.01 | <0.03 | <0.01 | <0.01 |
| | II | July 7 | | 0.15 | | | | | |
| | III | July 23 | | 0.57 | | | | | |
| | IV | Aug. 24 | | 0.80 | | | | | |
| Humboldt | I | June 21 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | II | July 8 | | 0.09 | | | | | |
| | III | July 23 | | 0.28 | | | | | |
| | IV | Aug. 19 | | 0.40 | | | | | |

ammonium sulphate (12), it would seem that mono-ammonium phosphate or other soluble phosphates containing little or no calcium are very suitable carriers. Until general nitrogen deficiencies on brown and dark brown soils occur, an increase in the proportion of nitrogen to phosphorus in fertilizers of the ammonium phosphate type will be of no value, since the choice of ammonium phosphate as the best material available as a commercial fertilizer is based on the fact that it is not a calcium phosphate. In more humid regions, where nitrogen deficiencies may be a problem, the situation may be quite different.

A further implication lies in the fact that mono-ammonium phosphate and the calcium phosphates as in superphosphate differ in their availability as well as in their nitrogen content. Therefore, a comparison of fertilizer treatments, involving the use of a standard application of phosphate of different forms with varying amounts of nitrogen, is valueless for measuring nitrogen response. The nitrogen response will be complicated by a varying phosphate effectiveness, and only when the phosphate dressing is made with one uniform form of phosphate will a valid nitrogen response be measured. Many fertilizer tests will have to be reviewed from this aspect.

## PLANT WEIGHT AND PHOSPHORUS CONTENT

From Figures 1, 2, 3 and 4, it can be seen that there is a close correlation between total phosphorus content and yield of plant material, under the conditions of this experiment. This suggests that plant growth is limited by phosphorus, or that there is no "luxury" consumption of phosphate. It can also be demonstrated from the data that the phosphorus content of the plants in the early stages is higher than at later stages, possibly indicating higher requirements for actively growing tissue. We may conclude that the beneficial action resulting from the addition of phosphate fertilizer is largely due to the fact that the fertilizer phosphate enables the plant to make a more vigorous early start, the later growth being completed largely from phosphorus absorbed from the soil.

### *Soil Phosphorus*

An earlier paper from this laboratory (16) indicated that the fertilized crop took up appreciably more phosphorus from the soil than the unfertilized. The experiment reported here is the most recent one of a series in which this point has been carefully examined. In no case have we been able to verify statistically the earlier observation, and it is suggested that perhaps the earlier result was aberrant, and by no means the general rule. In this experiment, there were no significant differences between the average uptake of soil phosphorus at maturity for fertilized and unfertilized treatments. However, at earlier harvest dates, there were statistically significant differences between the amount of soil phosphorus taken up by the crop under different treatments, suggesting that comparisons of fertilizer uptake by subtracting the amount of nutrient taken up by a control plot may be in error. One difficulty in evaluating the importance of the variability in soil phosphorus uptake is the large standard error obtained in the statistical analysis, indicating large uncontrolled variations which may be masking real differences.

*Feeding from Adjacent Rows*

The data indicating the amount of tracer phosphorus, and hence fertilizer phosphorus, taken up by rows adjacent to the active rows, are given in Table 4.

The rows fertilized with inactive phosphorus adjacent to the row fertilized with radioactive phosphorus did not take up significant amounts of the tracer, and it is concluded that the root systems of two adjacent rows, 6 inches apart, are not intermingled in the vicinity of the original seed. This does not imply that wheat plants will not feed on fertilizer 6 inches away horizontally from the original seed, but does suggest that at the relatively shallow depth considered here—2 in.-3 in.—the root systems of adjacent rows do not compete for fertilizer sown with the seed. The fertilizer sown in one row is effective in that row only, with only very minor exceptions. It is also evident that in these particular experiments, no serious errors would be incurred by neglecting the loss due to fertilizer phosphorus taken up by adjacent rows.

*Effect of Radioactivity*

Recently, Scott-Russell and Martin (13) re-examined the possibility of injury to plants from radioactive materials used as tracers. They arrived at the conclusion that it is very possible to use radioactive isotopes in tracer experiments at levels harmful to plants, and therefore to give spurious results. Hendricks and Dean (6) had earlier explored this possibility and concluded that for $P^{32}$, there was a very comfortable margin of safety.

In estimating the amount of "active" fertilizer taken up by inactive rows, the above-ground parts of numerous plots have been harvested and weighed, permitting a direct comparison of the yield from active and inactive rows, all other factors being similar. These data are presented in Table 5.

At the first harvest date, some irregularity in germination had a slight influence on the results. Since the "active" row was of primary interest, the 6 feet of "active" row were chosen from the 9 feet available to give the most uniform section. It very occasionally happened that, in this way, sections of adjacent rows that had poor germination were taken. This may account for the higher values in the case of the "active" rows for the first harvest. The statistical analysis was according to Student's Pairing Method (5), using the values for the individual plots, by comparing the average yield of the two adjacent "inactive" rows with the yield of the "active" row.

The most likely treatments to suffer any possible injury from radiation in this experiment were those treated with the double rate of mono-ammonium phosphate. The absolute uptake of fertilizer phosphorus by the plants was highest for this treatment, and consequently, the tissues would have a higher concentration of the radioactive isotope in this treatment. The mean data for this treatment for all harvests at both locations are presented in Table 5 (b).

Examination of the data indicates no suggestion of any injury from the radioactive phosphorus, in comparing "active" and "inactive" rows, based on the weight of the above-ground parts. Since this comparison shows no

TABLE 5.—EFFECT OF RADIOACTIVE PHOSPHORUS ON PLANT GROWTH

*(a) First harvest, all treatments recorded*

| | Plant wt., gm./6-foot row | | | |
|---|---|---|---|---|
| | Birch Hills | | Humboldt | |
| | Active rows | Inactive rows | Active rows | Inactive rows |
| Ammonium phosphate—half rate | 10.9* | 10.0* | 13.9 | 10.2 |
| Ammonium phosphate—basic rate | 10.7* | 10.8* | 16.1 | 14.6 |
| Ammonium phosphate—double rate | 12.3* | 11.0* | 13.7 | 8.2 |
| Sodium phosphate | 10.5* | 10.6* | 14.4 | 11.6 |
| Mono-calcium phosphate | 9.6* | 9.8* | 14.1 | 12.4 |
| Dicalcium phosphate | 7.6* | 6.9* | 10.7 | 11.3 |
| Dicalcium phosphate + $Ca(NO_3)_2$ | 8.3* | 7.9* | 12.9 | 10.0 |
| Mean | 10.0 | 9.6* | 13.7 | 11.6 |
| L.S.D.—5 per cent pt. | 0.8 | | 1.9 | |

Mean of all treatments, both locations:
Active rows 11.8
Inactive rows 10.4
L.S.D. 5 per cent pt. 1.0

*(b) All harvests—ammonium phosphate, double rate only*

| | Plant wt. gm./6-foot row | | L.S.D. 5 per cent pt. |
|---|---|---|---|
| | Active rows | Inactive rows | |
| Birch Hills I | 12.3* | 11.0* | |
| II | 69.4 | 72.5 | |
| III | 143.4 | 139.2 | |
| IV | 189.9 | 189.2 | |
| Mean of 4 | 103.7 | 103.0 | 12.0 |
| Humboldt I | 13.7* | 8.2* | |
| II | 72.1 | 71.2 | |
| III | 97.4 | 86.3 | |
| IV | 123.2 | 124.6 | |
| Mean of 4 | 76.6 | 72.6 | 8.8 |
| Mean of all locations, all dates | 90.2 | 87.8 | 9.6 |

All figures the mean of 4 plots except those marked *, indicating mean of 3 plots.

differences even at maturity, we can safely conclude that no significant effects on growth resulted from the presence of the radioactive phosphorus in the tissues of the plant.

The data confirm the earlier conclusion that it is relatively easy to avoid plant injury using radioactive phosphorus in tracer amounts in field experiments.

## SUMMARY

An experiment is reported on the effects of rates and forms of phosphate on plant uptake of phosphorus on wheat under semi-arid conditions, with neutral to alkaline soils containing high levels of calcium. From the data, it is concluded that:

1. Increasing the rate of application of mono-ammonium phosphate gives greater fertilizer phosphate uptake, but decreases the percentage of fertilizer utilized.

2. In comparing various carriers of phosphate at the same rate of applied phosphorus, the carriers arranged themselves in order of effectiveness as follows:

i. Mono-ammonium phosphate,
ii. Mono-sodium phosphate,
iii. Mono-calcium phosphate,
iv. Dicalcium phosphate plus calcium nitrate,
v. Dicalcium phosphate.

The dicalcium form was relatively ineffective, while mono-calcium phosphate was moderately available. The most effective forms were those without calcium, the mono-ammonium and mono-sodium salts, indicating that lower availability is probably related to the ease and rapidity of conversion to the difficultly available tri-calcium phosphate. In comparing similar phosphate carriers with and without nitrogen, the importance of the nitrogen on the effectiveness of the fertilizer was apparently small under the conditions of the experiment.

3. The total phosphorus taken up by the plant shows a good correlation with amount of growth, with evidence that the younger plants have a higher relative phosphorus content than plants at later stages of growth. However, any "storage" of phosphorus in the early stages does not account for the increased growth of the mature plant, but rather, it seems likely that since growth and phosphorus uptake are more or less parallel, increased uptake in the early stages means a higher final uptake, with a correspondingly greater growth.

4. One row of plants does not feed appreciably on fertilizer applied with the seed in adjacent rows 6 inches apart under the conditions of this experiment.

5. The effect on plant growth of radiation, and of radioactive phosphorus taken into the plant, is negligible. There is no evidence of injury from tracer phosphorus used in reasonable amounts in the field.

## ACKNOWLEDGMENTS

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# EXPERIMENTS IN THE CONTROL OF SIMULIUM ARCTICUM MALLOCH BY MEANS OF DDT IN THE SASKATCHEWAN RIVER[1]

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## INTRODUCTION

The river-breeding black fly, *Simulium arcticum* Mall., has been responsible in recent years for heavy losses of live stock throughout an area of approximately 10,000 square miles in the north-central agricultural area of Saskatchewan (4). These losses always occur in late May or early June as the result of the sudden emergence and mass flights of the flies. Protection of live stock from these flights has been difficult because it is almost impossible to predict the time and place at which an attack will occur. Additional flights, which occur in midsummer, have never caused serious losses of live stock.

The immature life-stages of the flies which form these outbreaks develop on scattered, extensive, rocky areas in the swiftly flowing waters of the relatively large North and South Saskatchewan Rivers. These breeding areas (Figure 1) occur at varying intervals throughout a distance of over 40 miles in the North branch between Prince Albert and the confluence with the South branch, and for a distance of over 175 miles in the South branch from Saskatoon to the confluence. The most important of these are at Fish Creek, Fenton and Prince Albert.

Results of investigations over a period of years have shown that the only certain method of preventing outbreaks is to eliminate the larvae of the first generation. The period when larvae only are present in the streams is short, about three weeks, and usually comes in the middle of May, but may be delayed into the latter part of May.

The field tests described in the paper were designed primarily to determine the practicability of treating the Saskatchewan River with DDT as a means of preventing the destructive spring fly flight of *S. arcticum*.

In 1948 the level of the rivers was considerably above normal, owing to exceptionally heavy precipitation in winter and early spring. As a result, many rocky beds, commonly inhabited by black fly larvae, were covered to a depth that made examination difficult. The marked increase in siltiness of these normally muddy rivers also contributed to the difficulties inherent in these investigations. However, accessible infested breeding areas were available in the Fish Creek area of the South Saskatchewan.

The field tests were a part of the black fly investigations being carried out from the Dominion Entomological Laboratory at Saskatoon, and the Department of Biology, University of Saskatchewan, and were made with the co-operation of the Suffield Experimental Station of the Defence

[1] Contribution No. 2608 from the Division of Entomology, Science Service, Department of Agriculture, and contribution from National Defence Research Board, and from the Department of Biology, University of Saskatchewan.

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FIGURE 1. Map of the North and South branches of the Saskatchewan River. The rapids in the South Saskatchewan, in which the six stations for the first experiment were established, are indicated, as well as some of the major rapids studied between Prince Albert and Nipawin. The points of application of the insecticide at Fish Creek and at Prince Albert are shown.

Research Board. The latter provided equipment and personnel for the preparation and application of the insecticide, while members of the Saskatoon laboratory and of the University carried out the biological studies.

## GENERAL PROCEDURE

The application of DDT in small concentrations has been found effective in the control of black fly larvae in small streams (1). It was decided, therefore, to test the effectiveness of DDT as a larvicide against *S. arcticum* in the Saskatchewan River. Applications by means of aircraft were carried out at Fish Creek on May 25 (Figure 2), and at Prince Albert on June 1. At this time 85 per cent of the larvae were in the first or second instar.

The spray consisted of a 12 per cent solution of DDT (technical grade) dissolved in one part of Velsicol AR50 (an alkylnaphthalene solv nt) and nine parts of fuel oil No. 2. The solution also contained 0.5 per cent of Triton X-100 emulsifier to facilitate its dispersal on the river water, and 0.5 per cent of Williams red dye so that the spray would be visible and its fate could be followed.

For spray application, 500 gallons of the solution were loaded into two tanks (B-25 jettisonable fuel tanks) mounted in the fuselage of a Dakota (C-47) aircraft. The spray was emitted through a vertical pipe, 4 inches in diameter, projecting 18 inches below the belly of the aircraft into still air outside the slipstream. The average rate of emission was three gallons (Imperial) per second, with the aircraft flying at the set speed of 150 miles per hour. This is equivalent to 1 gallon for every 25 yards of flight. The spray was broken up on emission into droplets with a wide range of sizes, whose median diameter (by mass) was approximately 300 microns (0.3 mm.).

Applications were performed in the early morning, while the air was stable and there were no upward convection currents. The emission runs were made across the river on a track slanted diagonally in order to allow a convenient length of run. A number of runs were made over the same track established by ground markers (luminescent fabric panels), dictated by the dosage required. The river flow ensured that a new stretch of water was presented each time for reception of the spray. Emission runs were made every two to three minutes, the time required for the aircraft to make a complete circuit. Instructions as to height of flight, duration of emission, and number of runs, were relayed to the aircraft by radio from the ground.

Samples of the river water, each of two litres, were taken a few miles downstream from the point of application. The red dye in the solution served to indicate when the treated water was passing the sampling point. Water markers of powdered aluminum were also used, but were found to be ineffective for this purpose. The samples were taken just below the surface, and at a depth of four feet, at points established in midstream, as well as close to either bank. Subsequently, they were evaporated to dryness, the DDT was extracted with acetone, and the amount present determined by the Schechter-Haller method.

To assess the results of each treatment, sampling stations were established in the rivers prior to the applications. Each station consisted of a staked transect across an infested rapid. Four quantitative stations and three qualitative stations were set up in the South Saskatchewan River. Figure 1 indicates the location of these stations. The pre-application surveys of these stations were made two and three days prior to the application. Post-application surveys were made 1 day and 16 days after the application.

For the second experiment, in the North branch, 5 stations were established (Figure 1). Two of these were above the junction with the South Saskatchewan, and 3 below the junction, the most distant being 107 miles down river from the point of application at Prince Albert. In this experiment the stations were also sampled just prior to the application. The post-treatment surveys were made 1 day and 4 days after the application. In this case, however, adequate sampling was difficult because of the unusually high level of the river.

At each quantitative station the black fly population was sampled by collecting 30 to 50 rocks from depths of 6 to 30 inches along the staked line. Direct observation being impossible, because of the siltiness of the river, rocks were collected by hand in the shallow water. In the deeper water the collections were made with the aid of an anchored boat and a modified Peterson dredge. After each collection was completed, the rocks were washed off, the black fly larvae and other organisms were allowed to settle out, and then the superfluous water was decanted off. The samples were preserved in formalin. The estimates of larval populations in the quantitative samples were made in the laboratory. In those cases where the poputions were too large for a direct count, a portion of the sample was selected at random, counted and weighed. The remainder of the sample was then weighed and the number of larvae in the whole sample estimated. A uniform dryness for the weighed samples was obtained by drying the larvae just to the point where they no longer produced a wet mark on dry filter paper. Since the total area which the sample represented was known, it was then possible to determine the population density per square foot. No attempt was made to sample organisms in places other than those suitable for black fly larvae. The results, therefore, cannot be considered indicative of the effect of the treatment on insects living on silt and sand bottoms.

The possible effect of DDT on fish is of importance. A small amount of angling and netting is done along the entire river. The goldeye (*Amphiodon alosoides* Raf.) is of considerable economic importance. The effect of the field applications on native river fish: pickerel (*Stizostedion vitreum* (Mitch.) ), common sucker (*Catostomus commersonii* (Lac.) ), river chub (*Platygobio gracilis* (Rich.) ), ling (*Lota maculosa* (Le Sueur) ), and goldeye, was studied by members of the Department of Biology of the University of Saskatchewan. Field tests in the spring indicated that concentrations of DDT as high as 25 p.p.m. for 30 minutes had no noticeable effect upon the common river fish.

(Photograph of aircraft applying DDT)

FIGURE 2. Aircraft (C47) applying DDT to the South Saskatchewan River at Fish Creek. The direction of flight is indicated by the two markers. The river and river valley are typical of the Saskatchewan River. Stations 2a and 2b are located in rapids at the point on the right bank visible in the distance.

## EXPERIMENT ON THE SOUTH SASKATCHEWAN RIVER

The river channel of the South Saskatchewan River has a uniform width and a steady gradient. There are no important tributaries in the area involved in this experiment, nor does the river flow through any lakes or marshes. At the time of the spray application the water temperature was 61° F., with a pH of 7.28 and total solids of 13.9 p.p.m.

The application of the insecticide at Fish Creek (Figure 2) was carried out on May 25, 1948, between 8.10 and 8.46 a.m. The sky was clear and the wind was blowing downstream at speeds from $2\frac{1}{2}$ to 4 miles per hour. The river at this point was 400 yards wide; the emission track was slanted diagonally across the river to give a water distance of 700 yards. The spray was emitted in 16 runs, each of 9 seconds' duration, made at a height of 150 feet above the river. During the total emission period of 144 seconds, 440 gallons were emitted over the river, containing 615 pounds of DDT.

The volume flow of the river at the point of application, as determined from records supplied by the Dominion Water and Power Bureau, was 35,220 cubic feet per second, equivalent to 13.2 million gallons per minute. Therefore, during the 36 minute period of application, 474 million gallons (4740 million pounds) of water were treated. The application to it of 615 pounds of DDT was, therefore, equivalent to 0.13 parts of DDT per million parts of water.

The speed of the water in the middle of the river was 3.5 miles per hour. Thus, in the $2\frac{1}{2}$ minute interval between successive emission runs it flowed 300 yards downstream. The width of the swath of spray deposited was about 100 yards, leaving 200 yards of clear water between each swath. However, the swaths were observed from the air to fuse at the first rapids two miles downstream, and thereafter to move down the river as a continuous film, broken only in small spots as boils of water came to the surface.

The treated water first arrived at the sampling point, located at Fish Creek Ferry five miles downstream, 80 minutes after application was commenced. It continued to flow past for a period of 60 minutes, indicating that its length was 3.5 miles, as compared with the 2.1 mile length of water treated. Thus in travelling 5 miles the added material is diluted by a factor of 1.7. The content of DDT in the water, tabulated below, varied from 0.01 to 0.09 parts per million, the highest concentration occurring at the forward end of the film and in the middle of the river.

TABLE 1.—CONTENT OF DDT IN P.P.M. IN RIVER, FISH CREEK FERRY

| Time of sample | North bank | | Midstream | | South bank | |
|---|---|---|---|---|---|---|
| | Surface | Deep | Surface | Deep | Surface | Deep |
| 0935 hr. | 0.012 | Trace | 0.058 | 0.085 | 0.000 | 0.000 |
| 0955 hr. | 0.017 | — | 0.044 | 0.019 | 0.017 | 0.011 |
| 1010 hr. | 0.018 | 0.020 | 0.017 | 0.016 | 0.020 | 0.026 |
| 0900 hr. | Control sample taken before passage of insecticide: 0.00 | | | | | |

TABLE 2.—THE EFFECTS OF DDT APPLICATION ON POPULATIONS OF BLACK FLY LARVAE IN THE SOUTH SASKATCHEWAN RIVER ON MAY 25, 1948

| Station | Depth (inches) | Distance from point of application | Larvae per square foot | | Per cent reduction | Per cent survival* | Larvae per square foot June 10 |
|---|---|---|---|---|---|---|---|
| | | | May 23 and 24 | May 26 and 27 | | | |
| 1 | 0–30 | 4.9 miles upstream | 5649 | 3010 | 46.7 | — | — |
| 2a | 12–24 | 1.25 miles downstream | 3390 | 46 | 98.8 | 2.6 | 159 |
| 2b | 8–24 | 1.25 miles downstream | 8840 | 11 | 99.9 | 0.2 | 353 |
| 3 | 8–30 | 17 miles downstream | 1780 | 2 | 99.9 | 0.2 | 42 |
| 4 | 8–30 | 56 miles downstream | Not examined before application | 0 | — | — | 3 |
| 5 | 6–30 | 58 miles downstream | Very heavy concentration of larvae on willow stems | 0 | 100 | 0.0 | — |
| 6 | 6–26 | 92 miles downstream | Not examined before application | Trace | — | — | — |

* Percentage survival $=\frac{A_2}{A_1}\frac{C_1}{C_2}$ 100 (Hoffman & Surber, 1945),
when $A_1$=pre-treatment population in treated area
$A_2$=post-treatment population in treated area
$C_1$=pre-treatment population in check area
$C_2$=post-treatment population in check area

TABLE 3.—THE EFFECTS OF DDT APPLICATION ON ARTHROPODS OTHER THAN BLACK FLY LARVAE IN THE SOUTH SASKATCHEWAN RIVER ON MAY 25, 1948

| Station | Depth (inches) | Distance from point of application | Population per square foot | | Per cent reduction | Per cent survival† | Population per square foot, June 10 |
|---|---|---|---|---|---|---|---|
| | | | May 23 and 24 | May 26 and 27 | | | |
| 1 | 0–30 | 4.9 miles upstream | 0.52 | 0.58 | — | — | — |
| 2a | 12–24 | 1.25 miles downstream | 0.58 | 0.08 | 86.2 | 12.3 | — |
| 2b | 8–24 | 1.25 miles downstream | 0.40 | 0.09 | 77.5 | 20.1 | 0.45 |
| 3 | 8–30 | 17 miles downstream | 0.29 | 0.27 | 6.9 | 83.5 | 0.16 |

† Calculated as for Table 2.

Virtually complete disappearance of black fly larvae was observed at the Fish Creek Rapids by the time all the treated water had passed this point. A thorough examination four hours later revealed only an occasional live larva where there had been immense numbers prior to treatment. The effects of the treatment on the black fly larvae are presented in Table 2.

The data obtained from Stations 2a, 2b, and 3 show that the larvae were almost completely eliminated from the river for a distance of 17 miles downstream from the point of application. There were also strong indications that the insecticide was effective at much greater distances as shown by the data obtained at Stations 4, 5 and 6. At Stations 4 and 5, located in the Fenton Rapids over 50 miles below Fish Creek, not a single larva could be found two days after the application. Nine days earlier submerged willows at Fenton were exceptionally heavily infested. Long strands of twisted silk were all that remained to indicate that larvae had been present. At station 6 over 90 miles downstream from Fish Creek, only four larvae were found in a two-hour search. Unfortunately no pre-application survey had been made at this station. It would appear to be significant that two days following the application of DDT at Fish Creek no black fly larvae were found in any rapids below the point of treatment as far as the junction with the North branch, a distance of more than 100 miles. These are the rapids that are normally severely infested with larvae that contribute heavily to the mass flights every spring. Collections below the junction indicated that the dilution had rendered the insecticide ineffective here.

It should be pointed out that the reduction in population shown in Table 2 for Station 1 is believed to reflect a sampling error, rather than an actual change. Sampling at this location was rendered difficult because of the large size of rocks. Even when allowance is made for a natural reduction of this magnitude at the control station, the degree of effectiveness is virtually unchanged.

Within two weeks after the application of the insecticide at Fish Creek, the rapids in the upper end of the cleared section of the river became repopulated with small numbers of mature black fly larvae. Most of the larvae originated in the heavily infested rapids up river from the point of application. On July 27, rapids at Fish Creek and at Fenton, where Stations 2a, 2b and 5 had been located, were re-examined. The entire treated section of the river was found to be populated with second generation larvae. At Fish Creek, where the infestation was heaviest, the population was counted as 4 pupae and about 100 larvae per square foot. At Fenton the examination was the first thorough work of the year, because of the unusually high water level which had prevailed earlier in the season. Previous examinations had been confined to the submerged willows near the banks. On July 27 the river level was considerably lower than at any previous time since the ice break-up and wide areas of the rock beds were exposed. A small number of empty black fly cocoons was found on the prominent boulders in the area. There were approximately 30 of these large boulders exposed in the rapids and they contained fewer than 100 empty cocoons per square foot. Very few pupae were found on the countless number of smaller boulders. From these observations it was evident that there had been considerably less pupation in these rapids than in the previous year.

The elimination of black fly larvae from all of the main breeding areas in the South Saskatchewan River may have prevented an outbreak of major proportions during the spring of 1948. In June, when the remainder of the first generation of black flies had almost entirely emerged, very few black flies could be found on live stock in the vicinity of the treated portion of the South Saskatchewan, whereas the usual large swarms could be found attacking live stock adjacent to untreated portions of the river at Saskatoon and Vonda. Extensive black fly flights were absent for the first time in five years.

The effect of the treatment on aquatic arthropods, other than black fly larvae, was observed immediately after the application. Small numbers of Plecoptera and Ephemeroptera nymphs were found floating in the oil film which lingered in the back-waters below Fish Creek. The data in Table 3 show the extent to which these aquatic insects were affected by the treatment. Their numbers were reduced by 86 per cent and less, near the point of application, and by 7 per cent at a distance of 17 miles downstream.

Laboratory experiments completed later in the year provided additional information as to the effect of DDT on some of these aquatic organisms. Amphipods (an important source of food for fish in the Saskatchewan River) were permanently paralyzed by two-hour exposures to oil emulsions of DDT in concentrations as low as 0.05 p.p.m. With thirty-minute exposures no disabling effects were observed at concentrations less than 0.5 p.p.m.

The fish, of several species, which were confined in cages a short distance downstream from the point of application, or which were observed free in the river, were found to be entirely unaffected by the treatment. Fuller details on this point are given in a report (3) by D. S. Rawson, Department of Biology, University of Saskatchewan.

No dead fish were discovered anywhere during the black fly sampling work. The data obtained from experiments at this laboratory confirmed these observations. Using a DDT suspension in water, three species of river fish were entirely unaffected by the strongest treatment used, namely 25 p.p.m. for 30 minutes. The fish were also unaffected by DDT oil emulsion at the highest concentration, namely, 30 p.p.m. for 15 minutes. Additional experiments indicated that two species of river minnows were unaffected after an exposure of 30 minutes to concentrations as strong as 50 p.p.m. of technical grade DDT as a water suspension.

## EXPERIMENT ON THE NORTH SASKATCHEWAN RIVER

The physiography of the area (Figure 1), which is involved in this experiment, is similar to that of the South branch. The water temperature at the time of the experiment was 64° F. The pH and total solids were estimated to be similar to those on the South branch.

The insecticide was applied to the North Saskatchewan River at Prince Albert on June 1, 1948, from 8.23 to 8.57 a.m. The sky was clear and the wind was blowing obliquely across and down the river at 2 to 5 miles per hour. The river at this point was 500 yards wide; the emission track was angled slightly to give a distance of 700 yards. The spray was

emitted in 12 runs, each of 9 seconds' duration, at a height of 120 feet. During the total emission period of 109 seconds, 390 gallons were emitted, containing 545 pounds of DDT.

The volume flow of the river at the point of application was determined to be 63,900 cubic feet per second, or 23.9 million gallons per minute. Therefore, during the 34 minute period of application, 8100 million pounds of water were treated. The application of 545 pounds of DDT was, therefore, equivalent to 0.07 parts DDT per million parts of water.

The speed of the river was 2.1 miles per hour in midstream. In the interval between successive runs it flowed 180 yards downstream. The width of each swath of spray deposited was 40 yards. The series of swaths moved downstream as a succession of V's, due to faster movement in midstream. The swaths were observed to join into a continuous film at the weir $1\frac{1}{2}$ miles downstream from the point of application.

The treated water first arrived at the sampling point 3 miles below the point of application 55 minutes after the first emission run. It continued to flow past for 45 minutes, indicating that it was 1.5 miles long, as compared with 1.2 mile-length treated. Owing to the low content of DDT and the high content of suspended material, accurate determination could not be made of the water samples.

In this field test the application of DDT at the reduced rate of 0.07 p.p.m., over a period of 34 minutes, apparently had little effect on the black fly larvae. Unfortunately, it was impossible to establish satisfactory stations in heavily infested rapids as was done on the South branch, because of the extremely high level of the river. However, the observations at the stations which were set up indicated that there were no significant changes as a result of the application. Fish were also unaffected by this application (3).

## DISCUSSION AND CONCLUSIONS

The results of experiments conducted in the Saskatchewan River indicate that an oil solution of DDT, applied at the rate of 0.13 p.p.m. for a period of 36 minutes, resulted in the complete elimination of the larvae of *Simulium arcticum* for a distance of at least 17 miles. There is evidence that the treatment was effective for a distance of 90 miles. On the other hand, an application of 0.07 p.p.m. for a period of 34 minutes proved ineffective. These results are in general agreement as to time and dosage with those obtained at Churchill in 1947 (1). In the South Saskatchewan River experiment it was demonstrated that the concentration of DDT became progressively lower as the distance increased from the point of application. At the same time the exposure period progressively increased with the distance. This would explain how black fly larvae were successfully eliminated in the South branch at the greater distances from the point of application.

The rapids in the upper end of the treated section of the river became lightly repopulated with mature black fly larvae within two weeks after the application. This was the result of a migration of larvae downstream from infested rapids above the point of application. Later in the season the entire treated section of the river became repopulated with second

generation larvae. Few adults, however, were collected during the summer months in the vicinity of the treated section of the river. This is the area which in recent years had suffered heavy live stock losses due to black fly outbreaks.

The effects on the black fly larvae of the inert components in the insecticide were studied in a small-scale field experiment. The results indicated that the DDT was the principal active ingredient in the insecticide.

From the results obtained in these tests it may be concluded that practical control of *Simulium arcticum* may be secured by the application of DDT to the Saskatchewan River in sufficient quantity to produce a concentration of not less than 0.1 p.p.m. for a period of over half an hour. A lower concentration without a corresponding increase in the exposure time would be ineffective. At the effective dosage level virtually complete elimination of larvae in the river for a distance of at least 17 miles and possibly for a much greater distance would be possible. Therefore, one application at Prince Albert on the North branch, and two or three along the South branch down river from Saskatoon, should be sufficient to eliminate infestations from all the main breeding areas from which destructive outbreaks have originated in the past.

Such treatments would be non-lethal to fish. River fish showed no ill effects from either of the two spray applications, and laboratory tests indicated that several species of fish native to the Saskatchewan River could withstand dosages which were several times greater than those which were effective against the black fly larvae. Aquatic insects, other than black fly larvae, were affected during the field tests by the DDT, but to a lesser degree. Their survival may, in part, be attributable to habits which provided them with greater protection from contact with the insecticide.

The cost of this method of black fly control is well within practical limits, in view of the fact that a lethal dosage may be established with a relatively small quantity of insecticide, and that a single application is effective for a considerable distance in the river. It should be pointed out that the volume discharges of the two branches of the Saskatchewan River at the time of the applications were three and seven times greater than average. Thus the amount of insecticide normally required would be considerably less than that used in these control tests.

## SUMMARY

Virtually complete clearance of a large river, the South Saskatchewan, of larvae of *Simulium arcticum* Mall., for a proven distance of 17 miles, was obtained by the application of sufficient DDT in an oil solution from an aircraft to give a calculated concentration of 0.13 p.p.m. for a period of 36 minutes. There is evidence that the lethal effect of this application extended down river for 90 miles. Other aquatic insects were affected to a lesser degree. Fish were entirely unharmed. The application of 0.07 p.p.m. of DDT to a similar river, the North Saskatchewan, had little effect on the black fly larvae.

## ACKNOWLEDGMENTS

The two field experiments recorded in this paper involved the co-operation of several departments. These are mentioned elsewhere.

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# TESTING CEREAL VARIETIES FOR DORMANCY[1]

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Dormancy, or "after ripening"* of grain, is important in those regions where prolonged moist weather conditions may occur at harvest. Large losses have been sustained on the plains of Western Canada when wet harvest weather has caused sprouting in swathed and stooked grain awaiting threshing. To protect the farmer and others dependent upon agriculture from these losses it is desirable to have cereal varieties which will remain dormant for several weeks after maturity regardless of the favourableness of the circumstances for germination. Varieties differ very markedly for dormancy and accurate tests are available for the determination of their comparative merits. However, the plant breeder needs tests which are not only accurate but cheap and easy to make. In 1947 and 1948 methods of testing dormancy were studied at Saskatoon with a view to possible simplification.

## REVIEW OF LITERATURE

Differences among wheat varieties in their tendency to sprout in the swath or stook have been reported by Deming and Robertson (2), Akerman (1), Feekes (3), Harrington (5), Greer and Hutchinson (4) and others. Harrington and Knowles (6, 7) in 1937 and 1938 studied the dormancy of 110 varieties and hybrid lines of wheat and barley and found large varietal differences in both crops. They also developed a laboratory technique which gave results closely similar to those secured under field conditions at Saskatoon in 1938. They showed that dormancy was an inherited character probably governed by more than one pair of factors.

Hutchinson, Greer and Brett (8), working with wheat, reported in 1948 that they found varietal differences both in seed and ear sprouting at different dates after maturity and they concluded that the ear exerts a restrictive influence on the germination of the seed. Smith (9), also in 1948, showed that the presence of the outer glumes may retard germination considerably.

## MATERIALS AND METHODS

### *Tests in 1947*

In the fall of 1947, dormancy tests were made on 62 varieties of spring wheat, 7 of winter wheat, 26 of oats and 40 of barley using a modification of the Harrington-Knowles (6) procedure. Each variety was sampled in the field, sufficient heads at the "just ripe stage"** being taken at random from border rows of the replicated micro-plot yield tests to furnish material for duplicate 25 seed tests at each of 5, 10, 20, 40 and 60 days after maturity. Where tests of both unthreshed and threshed seeds were desired twice as many heads were harvested. The method of sampling was such as to insure a fair comparison of varieties.

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* "After ripening" is a state of dormancy of the embryo of the mature cereal seed in the presence of conditions favouring germination and is used synonomously with the term "dormancy" in this paper.

** When the kernel is indented with difficulty by the thumb nail.

The head material harvested from the field was stored on shelves in the greenhouse basement from maturity until required for germination tests. The storage temperature was close to 19° C. ± 2° and the humidity varied between 68 per cent and 88 per cent. Half of the heads were used for the unthreshed seed tests and half for the threshed seed tests where both were made. In the unthreshed wheat seed tests 3 or 4 half heads were used for each duplicate sample. In making each test duplicate lots each containing 25 seeds (excepting in some instances where the portions of heads in the unthreshed seed test had one or two seeds more or less than 25) which had been ripe for the desired number of days, were placed on inch-deep beds of moist river sand on the greenhouse basement floor where the average temperature was about 18° C. The seeds were then covered with several layers of moist muslin cloth. Water was added daily as required. Readings on germination were made at 5, 10 and 15 days after the start of each test.

All of the varieties of spring wheat were given an unthreshed seed test and seven of them also had a threshed seed test; the winter wheats were all tested both threshed and unthreshed; 13 oat varieties were tested both threshed and unthreshed, but the other 13 varieties only in the unthreshed condition; all of the barleys were tested threshed.

Summarization of the data was effected on the basis of considering germination in excess of 40 per cent as constituting emergence from dormancy. This arbitrary dividing line was checked against others such as 30 per cent and 50 per cent and it was concluded that 40 per cent was the most satisfactory figure to use.

*Tests in 1948*

The 1948 germination tests were made on both threshed and unthreshed seed of 12 varieties of spring wheat and 8 varieties of oats, and on threshed seed of 8 varieties of barley. The procedure of sampling, testing and summarizing was the same as in 1947 with the following exceptions. For each test alternative spikelets were removed from each of ten heads. Half of the spikelets were used for a duplicate test of unthreshed seeds and the other half for a duplicate test of threshed seeds. After the seed was placed on the moist sand it was covered with a square of moist blotting paper containing the number of the sample. Over these were spread several thicknesses of moist muslin cloth. Germination tests were started on all samples at 5, 10, 20, 30, 40, 50 and 60 days after maturity and for wheat at 70 days in addition. Readings on the threshed seed tests were made at 3, 5, 8, 10 and 15 days after the start of a test. For the barley and oat tests the lots of seed were placed for germination at 5, 10, 20, 35; 50 and 60 days after maturity.

In addition to the use of moist sand beds on a basement floor extensive trials were made using Petri dishes with moist sand or blotting paper in our Cereal Breeding laboratory at temperatures of 19° to 24° C. These tests were not satisfactory, one of the main disturbing factors being moulds. The basement tests in river sand were free from mould interference.

## RESULTS IN 1947

The nature and range of the dormancy results are illustrated by the percentage germination data on eight varieties as given in Table 1. For example, Garnet wheat, a variety with very little dormancy, germinated 40 per cent when the unthreshed seed was kept dry for 5 days after maturity and then was placed in moist sand for 10 days, whereas Apex did not germinate as much as 40 per cent until the unthreshed seed had been ripe for 60 days and then was kept in moist sand for 15 days.

TABLE 1.—DORMANCY DATA ON UNTHRESHED SEEDS OF EIGHT OF THE 62 SPRING WHEAT VARIETIES TESTED IN 1947, TO ILLUSTRATE THE NATURE AND RANGE OF THE RESULTS

| Days after maturity | Days after start of test | Germination percentages of varieties | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C.A. 11-101 | Apex 1789 | Thatcher | Marquis | Regent | Garnet | Rescue | Reliance |
| 5 | 5 | 0 | 0 | 0 | 0 | 0 | 27 | 0 | 0 |
| | 10 | 0 | 0 | 1 | 0 | 0 | 40 | 2 | 0 |
| | 15 | 0 | 1 | 9 | 0 | 0 | 47 | 6 | 1 |
| 10 | 5 | 0 | 0 | 0 | 0 | 0 | 86 | 0 | 4 |
| | 10 | 0 | 0 | 1 | 0 | 2 | 90 | 2 | 5 |
| | 15 | 0 | 0 | 3 | 0 | 2 | 90 | 14 | 6 |
| 20 | 5 | 0 | 0 | 1 | 0 | 0 | 96 | 0 | 0 |
| | 10 | 2 | 0 | 2 | 0 | 0 | 99 | 0 | 1 |
| | 15 | 4 | 0 | 6 | 0 | 0 | 99 | 5 | 8 |
| 40 | 5 | 1 | 0 | 49 | 10 | 55 | — | 95 | 63 |
| | 10 | 6 | 0 | 62 | 26 | 68 | — | 95 | 66 |
| | 15 | 8 | 0 | 69 | 51 | 78 | — | 98 | 66 |
| 60 | 5 | 2 | 0 | 68 | 16 | 41 | — | — | — |
| | 10 | 2 | 22 | 91 | 34 | 81 | — | — | — |
| | 15 | 2 | 43 | 93 | 54 | 88 | — | — | — |

TABLE 2.—SUMMARIZED DORMANCY OF UNTHRESHED SEEDS OF 62 VARIETIES OF SPRING WHEAT IN 1947

| Variety rank | Number of days of dormancy* | | | Varieties and hybrid lines‡ |
|---|---|---|---|---|
| | 5 | 10 | 15 | |
| 1 | 60† | 60† | 60† | Comet-Apex 11; CA 11-101 |
| 2 | 60† | 60† | 60 | Apex 1789 |
| 3 | 60 | 60 | 60 | Red. Sel. 169; Redman 154 |
| 4 | 60† | 60† | 40 | Marquis |
| 5 | 60† | 60 | 40 | Apex 2156; Reg. Can. 918; Reliance C |
| 6 | 60 | 60 | 40 | Apex 2177; Mida; Mida-Cadet 609; 3 lines |
| 7 | 60† | 40 | 40 | Regent × That. 171; CA 11-37; 700 × Apex 2194 |
| 8 | 60 | 40 | 40 | Thatcher; Saunders; 8 lines |
| 9 | 40 | 40 | 40 | Rescue; Reliance; Red Bobs; Regent; 29 lines |
| 10 | 10 | 5 | 5 | Garnet |

* The number of days which elapsed after maturity before exposure to germination conditions for 5, 10 or 15 days, respectively, resulted in more than 40 per cent germination. A † sign indicates a still longer dormancy, in other words the seed was still dormant after 60 days of dry storage.

‡ Abbreviations: CA = Comet-Apex; Red. Sel. = Redman Selection; Reg.-Can. = Regent-Canus; That. = Thatcher.

*Spring Wheat*

The results on the dormancy of unthreshed seed of 62 varieties of spring wheat are summarized in Table 2. The seed of Comet × Apex 11 and Comet × Apex 11 Selection 101 germinated less than 40 per cent even when stored dry for 60 days after maturity and then exposed to conditions favourable for germination for 15 days. Apex, Redman, Selections of Apex, Redman and Reliance, Marquis, Thatcher, Mida, Mida-Cadet C.T. 609 and Saunders all showed long dormancy periods. Reliance, Regent, Rescue and Red Bobs showed from 45 to 55 days of dormancy.

*Oats and Barley*

Tests on the dormancy of threshed seed were made on 26 varieties of oats and 40 varieties of barley. The results are given in summarized form in Table 3. None of the oat varieties had as long dormancy periods as six of the barley varieties. Among the oat varieties Fortune and Garry showed dormancy of from 40 to 50 days. Vanguard, Valor and Overland ranked next in dormancy. Intermediate in dormancy were Banner, Ajax, Exeter, Beacon and Victory. Parkside and the hulless variety Brighton had the lowest rank with only 10 to 20 days of dormancy.

TABLE 3.—SUMMARY OF DORMANCY DATA ON THRESHED SEEDS OF 26 VARIETIES OF OATS AND 40 VARIETIES OF BARLEY IN 1947

| Variety rank | Number of days of dormancy* | | | Varieties and hybrid lines‡ |
|---|---|---|---|---|
| | 5 | 10 | 15 | |
| *Oats* | | | | |
| 1 | 35 | 35 | 35 | Fortune and Garry |
| 2 | 20 | 20 | 20 | Vanguard; Valor; Overland; Legacy; 2 lines |
| 3 | 10 | 10 | 10 | Banner; Ajax; Exeter; Beacon; Victory; 2 lines |
| 3 | 20 | 5 | 5 | Nakota × C 33-16; Nak.-Haj. 30 |
| 4 | 10 | 10 | 5 | Nakota × Haj. 25; Nak. Goph. 43 |
| 5 | 10 | 5 | 5 | Nak. × Haj. 31 |
| 6 | 5 | 5 | 5 | Parkside; Brighton; 4 lines |
| *Barley* | | | | |
| 1 | 50 | 50 | 50 | Warrior; TS 14-Peat. 25; Bran. 1360 |
| 2 | 50† | 50 | 35 | Glacier |
| 3 | 50 | 35 | 35 | Gem |
| 4 | 50 | 35 | 20 | MCB 179 |
| 5 | 50 | 20 | 20 | Velvon 11 |
| 6 | 35† | 20 | 20 | Bran. 1166 |
| 7 | 50† | 10 | 10 | MCB 163 |
| 8 | 20 | 20 | 20 | OAC 21; Vantage; Plush 1732; 3 lines |
| 9 | 20 | 20 | 10 | Newal; Tregal; MCB 173 |
| 9 | 35 | 10 | 5 | TS 14-Peat. 16 |
| 10 | 35 | 5 | 5 | Compana |
| 11 | 20 | 10 | 10 | Titan; Plush 1117; Regal; 3 lines |
| 12 | 20 | 10 | 5 | Frontier; Ottawa 94 |
| 13 | 10 | 10 | 10 | Montcalm; Feebar; Bay; 3 lines |
| 14 | 10 | 5 | 5 | TS 17-Peat. 10; US 5-37-1 |
| 15 | 5 | 5 | 5 | UA 46; UA 10; UA 24; TS 14-Peat. 21 |

* See footnote of Table 2.

‡ Abbreviations: Nak-Haj = Nakota-Hajira; Goph. = Gopher; TS = Trebi-Sol; MCB = Multiple Cross Barley; Bran. = Brandon; Peat. = Peatland; US = University of Saskatchewan; UA = University of Alberta.

The barley varieties ranking high for dormancy period were Warrior, Trebi-Sol × Peatland 25 (both hooded varieties), Brandon 1360, Glacier and Gem. Next in rank came Velvon 11 and Multiple Cross Selection 179-33. O.A.C. 21, Vantage, Plush, Newal, Tregal, Compana, Regal, Titan and Frontier were intermediate in dormancy. Montcalm, Feebar and Bay showed from 15 to 25 days' dormancy. Four new hybrid varieties, including three University of Alberta selections, had the lowest dormancy.

*Threshed versus Unthreshed*

Tests of both unthreshed and threshed seeds were made on 5 varieties of spring wheat, 7 of winter wheat and 13 of oats. The results are summarized in Table 4. In general the dormancy period of a variety was considerably longer when it was tested unthreshed. However, in some varieties there was little difference. In fact, Garnet spring wheat, Kharkov winter wheat and Ajax oats sprouted equally well whether threshed or unthreshed. This variation among varieties as to the protective influence of the chaff was not unexpected in view of results obtained by Luther Smith (9).

TABLE 4.—DORMANCY RESULTS ON THRESHED AND UNTHRESHED SEEDS OF 12 VARIETIES OF WHEAT AND 13 VARIETIES OF OATS IN 1947

| Variety | Unthreshed seeds | | | | Threshed seeds | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days of dormancy* | | | Variety rank | Number of days of dormancy* | | | Variety rank |
| | 5 | 10 | 15 | | 5 | 10 | 15 | |
| *Spring Wheat* | | | | | | | | |
| CA 11-2139 | 60† | 60† | 60† | 1 | 60 | 40 | 40 | 1 |
| CA 11-101 | 60† | 60† | 60† | 1 | 40 | 40 | 40 | 2 |
| Apex | 60† | 60† | 60 | 2 | 60 | 40 | 40 | 1 |
| Reliance | 40 | 40 | 40 | 3 | 40 | 20 | 20 | 3 |
| Garnet | 10 | 5 | 5 | 4 | 20 | 10 | 5 | 4 |
| *Winter wheat* | | | | | | | | |
| Kanred | 40 | 40 | 20 | 1 | 10 | 10 | 5 | 2 |
| McAlpine | 40 | 20 | 5 | 2 | 5 | 5 | 5 | 3 |
| Wh-Ry. Hyb. | 40 | 5 | 5 | 3 | 5 | 5 | 5 | 3 |
| Yogo | 20 | 10 | 10 | 4 | 20 | 5 | 5 | 1 |
| Dawson | 20† | 10 | 5 | 5 | 5 | 5 | 5 | 3 |
| Buffum | 10 | 5 | 5 | 6 | 5 | 5 | 5 | 3 |
| Kharkov | 5 | 5 | 5 | 7 | 5 | 5 | 5 | 3 |
| *Oats* | | | | | | | | |
| Fortune | 65† | 65† | 65† | 1 | 35 | 35 | 35 | 1 |
| Garry | 65† | 65† | 65† | 1 | 35 | 35 | 35 | 1 |
| Victory | 65† | 65† | 65† | 1 | 10 | 10 | 10 | 3 |
| Exeter | 65† | 65† | 65† | 1 | 10 | 10 | 10 | 3 |
| Vanguard | 65 | 65 | 65 | 2 | 20 | 20 | 20 | 2 |
| Banner | 50† | 50† | 50† | 3 | 10 | 10 | 10 | 3 |
| V.C. 15 | 50 | 35 | 35 | 4 | 20 | 20 | 20 | 2 |
| Valor | 35 | 35 | 35 | 5 | 20 | 20 | 20 | 2 |
| Beacon | 65† | 10 | 10 | 6 | 10 | 10 | 10 | 3 |
| Brighton | 20 | 20 | 20 | 7 | 5 | 5 | 5 | 4 |
| Legacy | 20 | 10 | 10 | 8 | 20 | 20 | 20 | 2 |
| Ajax | 10 | 10 | 10 | 9 | 10 | 10 | 10 | 3 |
| Parkside | 10 | 10 | 5 | 10 | 5 | 5 | 5 | 4 |

* See footnote of Table 2.

The dormancy rating of the varieties was not the same for unthreshed as for threshed seed tests. In the spring wheat varieties there was a very large range of dormancy and the "threshed" ranking for dormancy is almost identical with the "unthreshed" ranking. In the winter wheat results the variety Yogo is out of line in that it had an intermediate rating in the unthreshed seed test and a high rating in the threshed seed test. In addition, Dawson, Buffum and Kharkov all rated equally low in the "threshed" test but were clearly differentiated in the "unthreshed" test. In the oat results, Victory and Exeter ranked high for dormancy when unthreshed but only intermediate when threshed. In fact, Ajax, which ranked very low unthreshed, was as high as Victory and Exeter when threshed.

## RESULTS IN 1948

The 1948 tests were run for the purpose of improving on the testing technique; consequently relatively few varieties were used.

### *Spring Wheat*

The summarized results on 12 varieties of wheat are given in Table 5. Unthreshed seed of Comet × Apex 11 Selection 101 and Comet × Apex 11 Selection 19, Redman, Apex 2177 and Saunders remained dormant for 55 to 75 days after maturity. Garnet, Reliance and Red Bobs showed the shortest dormancy periods and the other varieties were intermediate. On the whole the "unthreshed" and "threshed" results agree very well as to varietal rank for dormancy. In general the unthreshed seed retained its dormancy approximately 20 days longer than did the threshed seed. All varieties showed a 5-day unthreshed seed dormancy when tested 5 days after maturity and all but Red Bobs retained their dormancy for 10 days in this test. Garnet and Reliance were the only varieties to lose their dormancy in 5 days when tested 10 or 20 days after maturity.

TABLE 5.—DORMANCY RESULTS ON THRESHED AND UNTHRESHED SEEDS OF 12 VARIETIES OF SPRING WHEAT IN 1948

| Variety or line | Unthreshed seeds | | | | Threshed seeds | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of days of dormancy* | | | Variety rank | Number of days of dormancy* | | | | | Variety rank |
| | 5 | 10 | 15 | | 3 | 5 | 8 | 10 | 15 | |
| CA 11-101 | 70 | 50 | 50 | 1 | 30 | 30 | 30 | 30 | 30 | 2 |
| CA 11-19 | 70 | 50 | 50 | 1 | 40 | 30 | 30 | 30 | 5 | 1 |
| Redman | 60 | 40 | 40 | 2 | 20 | 20 | 20 | 20 | 20 | 4 |
| Apex 2177 | 50 | 50 | 40 | 3 | 20 | 20 | 20 | 20 | 20 | 4 |
| Saunders | 50 | 40 | 40 | 4 | 30 | 30 | 30 | 30 | 30 | 3 |
| Thatcher | 40 | 30 | 20 | 5 | 20 | 20 | 10 | 5 | 5 | 6 |
| Hope-Tim | 40 | 10 | 5 | 6 | 20 | 20 | 5 | 5 | 5 | 7 |
| Marquis | 30 | 30 | 30 | 7 | 20 | 20 | 20 | 20 | 10 | 5 |
| Rescue | 30 | 20 | 5 | 8 | 20 | 10 | 10 | 10 | 10 | 8 |
| Red Bobs | 30 | 5 | 5 | 9 | 20 | 5 | 5 | 5 | 5 | 10 |
| Garnet | 20 | 20 | 10 | 10 | 20 | 10 | 5 | 5 | 5 | 9 |
| Reliance | 10 | 5 | 5 | 11 | 10 | 5 | 5 | 5 | 5 | 11 |

* See footnote of Table 2.

*Oats and Barley*

Threshed and unthreshed seed of 8 varieties of oats and threshed seed of 8 varieties of barley were tested. The results appear in Table 6. Valor oats ranked at the top for dormancy both in the unthreshed and threshed seed tests. Victory and Fortune were next in rank, while Ajax and Brighton were at the bottom for dormancy. There was definite inconsistency between the "threshed" and "unthreshed" results, yet the tests agreed excellently on varietal ratings. The barley results show Warrior with the top rank, and Trebi next. Montcalm is at the bottom and the other varieties show intermediate positions.

TABLE 6.—SUMMARIZED DORMANCY RESULTS ON 8 OAT AND 8 BARLEY VARIETIES IN 1948

| Variety | Unthreshed seeds | | | | | | Threshed seeds | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of days of dormancy* | | | | | Variety rank | Number of days of dormancy* | | | | | Variety rank |
| | 3 | 5 | 8 | 10 | 15 | | 3 | 5 | 8 | 10 | 15 | |
| *Oats* | | | | | | | | | | | | |
| Valor | 60† | 60† | 40 | 40 | 30 | 1 | 60 | 50 | 50 | 50 | 50 | 1 |
| Victory | 60† | 20 | 10 | 5 | 5 | 2 | 60 | 5 | 5 | 5 | 5 | 2 |
| Fortune | 60† | 20 | 5 | 5 | 5 | 3 | 60 | 5 | 5 | 5 | 5 | 3 |
| Beacon | 60† | 5 | 5 | 5 | 5 | 4 | 20 | 5 | 5 | 5 | 5 | 4 |
| Exeter | 60† | 5 | 5 | 5 | 5 | 4 | 20 | 5 | 5 | 5 | 5 | 4 |
| Clinton | 60† | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 |
| Ajax | 30 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Brighton | 30 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| *Barley* | | | | | | | | | | | | |
| Warrior | — | — | — | — | — | — | 60 | 60 | 60 | 50 | 40 | 1 |
| Trebi | — | — | — | — | — | — | 60 | 40 | 30 | 30 | 20 | 2 |
| Bran. 1360 | — | — | — | — | — | — | 40 | 40 | 40 | 20 | 20 | 3 |
| Plush 1732 | — | — | — | — | — | — | 20 | 20 | 20 | 20 | 20 | 4 |
| Newal | — | — | — | — | — | — | 20 | 20 | 20 | 20 | 10 | 5 |
| Vantage | — | — | — | — | — | — | 20 | 10 | 5 | 5 | 5 | 6 |
| Titan | — | — | — | — | — | — | 10 | 10 | 10 | 10 | 10 | 7 |
| Montcalm | — | — | — | — | — | — | 5 | 5 | 5 | 5 | 5 | 8 |

* See footnote of Table 2.

## SUMMARIZED RESULTS FOR MORE THAN ONE YEAR

The wheat results for 1947 and 1948, along with those obtained in 1937 and 1938 by Harrington and Knowles (6) are reasonably consistent for the five varieties tested in both periods. Apex averaged the highest in dormancy and for any two-year average ranked higher than either Marquis or Thatcher, which in turn ranked much higher than Reliance or Garnet.

Twelve wheat varieties were tested in both 1947 and 1948. (Tables 2 and 5). The results showed CA 11-101, Apex 2177, Redman, Saunders and Thatcher to have a longer dormancy period than Rescue, Hope-Timstein and Red Bobs. Marquis and CA 11-19 were intermediate in that they were not consistently with either of the two groups. Reliance and Garnet constitute the lowest group with Garnet definitely at the bottom.

Tests for both 1947 and 1948 are available for eight barley varieties (Tables 3 and 6). The results agree as to varietal ranking as follows: Warrior, Brandon 1360, Plush, Newal, Vantage, Titan and finally Montcalm at the bottom.

The oat varieties Fortune, Victory, Garry, Valor, Exeter, Beacon, Ajax and Brighton were tested in both 1947 and 1948 (Tables 3, 4 and 6). The ranking of these varieties in the unthreshed seed tests was fairly consistent in the two years, Brighton and Ajax being at the bottom and Fortune, Garry and Victory being at the top. Valor, however, varied from an intermediate variety in 1947 to the top in 1948. The threshed seed results were less consistent than the unthreshed in differentiating the moderately long and long dormancy varieties.

## RETURN TO DORMANCY IN OATS

In the 1947 oat tests, and to some extent in the 1948 tests, there were clear-cut instances of return to dormancy. In 1947, nine out of 26 varieties tested as threshed seed and eight of these plus two others, when tested as unthreshed seed, showed return to dormancy. In 1948, out of eight varieties one showed return to dormancy in the threshed seed test and three showed this tendency in the unthreshed seed test. This phenomenon is illustrated with a portion of the 1947 data in Table 7.

Return to dormancy was striking in some varieties and not apparent in others. Threshed seed of Victory had "emerged" (germinated over 40 per cent) from dormancy 10 days after maturity, then made a partial return to dormancy by 20 days after maturity. At 35 days after maturity Victory was again out of its dormancy but there was a tendency toward a return to dormancy 50 days after maturity, which, at 65 days after maturity, had materialized. Yet unthreshed seed of Victory showed no tendency to return to dormancy. Threshed seed of Valor emerged from dormancy 20 days after maturity but at 50 days after maturity showed some tendency to return to dormancy. Beacon showed a definite return to dormancy in the unthreshed seed test 20 days after maturity. Banner shows a striking return of dormancy in the threshed seed test 20 days after maturity and a less apparent return at 65 days after ripening.

## DISCUSSION

The need for conducting dormancy tests on cereal breeding material is again affirmed by the data obtained in the present study. In both years and with all three crops, the varieties ranged from short to long dormancy. Commercial field experience with short dormancy varieties, such as Garnet wheat, has demonstrated that those varieties are as unreliable and likely to cause large economic loss as are varieties which shatter readily or are susceptible to a disease which occasionally assumes epidemic proportions. It is desirable for a cereal breeder to make dormancy testing a part of his testing program so that he will not release a new variety which does not possess at least a moderately long dormancy period. Indeed, it would seem that the cereal breeder should consider dormancy as an important character in his breeding program. In each of the crops, wheat, barley and oats,

TABLE 7.—GERMINATION DATA ON BOTH THRESHED AND UNTHRESHED SEED OF SIX OF THE VARIETIES OF OATS GROWN IN 1947 IN WHICH A RETURN OF DORMANCY WAS FOUND

| Days after ripe | Days after test starts | Germination percentages of varieties | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Unthreshed seeds | | | | | | Threshed seeds | | | | | |
| | | Banner | Victory | Fortune | Valor | Beacon | Garry | Banner | Victory | Fortune | Valor | Beacon | Garry |
| 5 | 5 | 14 | 0 | 0 | 0 | 6 | 1 | 14 | 4 | 2 | 0 | 16 | 4 |
| | 10 | 19 | 0 | 0 | 0 | 11 | 9 | 16 | 4 | 2 | 0 | 18 | 6 |
| | 15 | 19 | 5 | 0 | 0 | 12 | 12 | 16 | 4 | 2 | 0 | 18 | 16 |
| 10 | 5 | 31 | 0 | 2 | 0 | 18 | 7 | 64 | 54 | 6 | 0 | 82 | 24 |
| | 10 | 31 | 0 | 4 | 3 | 42 | 14 | 64 | 54 | 8 | 2 | 84 | 26 |
| | 15 | 32 | 2 | 4 | 7 | 42 | 15 | 64 | 56 | 8 | 8 | 84 | 26 |
| 20 | 5 | 14 | 1 | 7 | 13 | 6 | 14 | 12 | 28 | 14 | 48 | 36 | 24 |
| | 10 | 20 | 1 | 7 | 16 | 6 | 19 | 12 | 28 | 14 | 50 | 46 | 34 |
| | 15 | 20 | 1 | 7 | 16 | 6 | 19 | 12 | 28 | 14 | 50 | 46 | 34 |
| 35 | 5 | 26 | 4 | 2 | 42 | 1 | 13 | 64 | 62 | 46 | 70 | 36 | 52 |
| | 10 | 33 | 10 | 8 | 51 | 2 | 15 | 64 | 68 | 52 | 76 | 36 | 52 |
| | 15 | 33 | 11 | 8 | 53 | 2 | 15 | 66 | 68 | 52 | 76 | 36 | 54 |
| 50 | 5 | 4 | 6 | 3 | 49 | 6 | 14 | 48 | 42 | 70 | 52 | 18 | 52 |
| | 10 | 9 | 16 | 10 | 54 | 12 | 20 | 48 | 46 | 70 | 54 | 20 | 54 |
| | 15 | 9 | 19 | 15 | 54 | 13 | 20 | 50 | 46 | 70 | 54 | 20 | 54 |
| 65 | 5 | — | 23 | 7 | 28 | 11 | 4 | 22 | 26 | 58 | — | 64 | 40 |
| | 10 | — | 33 | 7 | 28 | 20 | 4 | 22 | 26 | 60 | — | 72 | 42 |
| | 15 | — | 33 | 7 | 28 | 21 | 4 | 24 | 26 | 60 | — | 72 | 42 |

there are varieties available which can supply the genes necessary for long dormancy. Some examples are: Apex and Redman wheat, Warrior and Brandon 1360 barley and Fortune and Garry oats.

It is of particular interest that varieties recently originated by the Field Husbandry Department of the University of Saskatchewan, where satisfactory performance in a dormancy test is considered a required character in the breeding program, rate very highly for length of dormancy period. These varieties are Apex and C.A. 11 wheat, Valor and Fortune oats and Warrior barley.

*Effect of Chaff on Germination*

The effect of the chaff in retarding germination has been discussed by Smith (9) and by Hutchinson, Greer and Brett (8). The effect was pronounced in the present study in both wheat and oats but not in all varieties. Three of the winter wheat varieties tested in 1947 (see Table 4) sprouted readily when tested as threshed seed but showed several weeks of dormancy when tested with the glumes enclosing the seeds. On the other hand, Kharkov showed no protective effect of the chaff. In oats also the germination-retarding effect of the glumes differed with different varieties in both years. For example in 1947, Banner and Victory (Table 4) show pronounced effects whereas Ajax showed no retarding effect of the glumes. The striking difference in the reaction of Clinton oats in 1948 and of two of the winter wheats in 1947 makes one hesitate to place full reliance on a threshed seed test.

*Standard Dormancy Tests*

The testing of varieties for dormancy is time-consuming and expensive; consequently any legitimate abbreviation of time or work is highly desirable. Dormancy tests on unthreshed seeds of wheat and oats give a closer approach to actual weathering in the field than do tests on threshed seed. However, the results indicate that threshed seed tests easily separate varieties having short dormancy from those with long dormancy periods. With either unthreshed or threshed seed, the varieties react sufficiently differently in different years (as shown in Tables 2 to 6) to make it advisable to have results from material grown in two seasons before drawing definite conclusions as to variety ranking for dormancy. The results suggest that a dormancy test in a single season, using either unthreshed or threshed seed, provides safe discarding of the varieties with short after-ripening periods. The results further suggest that a two-year test, using either threshed or unthreshed seed, should give a reliable placing of a variety as to whether it has a long, moderately long, short or very short after-ripening period. Since the threshed seed tests are much easier to make and take approximately 20 days less time, it would seem that either a one- or two-year test of threshed seed should be used.

*Feasibility of Preliminary Abbreviated Tests*

The technique used for testing dormancy has involved starting germination tests at six to eight intervals after maturity and making germination counts thereafter in 5, 10 and 15 days, or oftener. While the information gained is valuable in securing a fairly complete picture of varietal response,

the results of the 1947 and 1948 studies have indicated that a substantially accurate picture of the relative ranking of varieties for dormancy might be obtained with an abbreviated test.

A suitable abbreviated preliminary test for spring wheat conceivably could be a five-day germination test made with seed held for 10, 20 and 30 days after maturity. The seed test 10 days after maturity would be expected to show which varieties have reasonably long dormancy periods and allow elimination of those with short periods. The seed test 20 days after maturity would be expected to pick out varieties with long dormancy periods in some seasons, whereas the test of seeds 30 days after maturity might be better in other seasons.

The efficacy of the proposed tests may be estimated by reference to the available 1947 and 1948 data. The 10 + 5 test (i.e. 10 days after ripe plus 5 days under conditions favourable for germination) would have singled out Garnet, Reliance, Red Bobs and Rescue in 1948 as varieties of short dormancy. The 20 + 5 test in 1948 would have grouped all of the other varieties as being satisfactory. The 30 + 5 test would have grouped C.A. 11-101, C.A. 11-19 and Saunders at the top. The abbreviated tests in question would have proven unsatisfactory for the 1947 wheat tests (see Table 4) since the five-day germination test would have been too short for the spring wheat and too long for the winter wheat varieties. Additional germination readings at three or four and eight or ten days would seem desirable.

An abbreviated preliminary test for oat and barley varieties could be the same as that suggested for wheat with some exceptions. A ten-day germination reading was much more differential than a five-day reading in 1947 on both oats and barley, and with oats in 1948 the three-day reading was more differential than the later readings.

Where it is desired to distinguish further among the longer dormancy varieties of any of the crops, germination readings could also be made at 10 and 15 days with a minimum of extra work. Actually it is of value to do this, since, under field conditions, periods of damp weather may continue for two weeks although usually they would be of much shorter duration.

Summarizing the discussion on abbreviated preliminary tests the following seem appropriate to suggest: For all three crops germination readings at 4 or 5 days, again at 8 to 10 days, and for some varieties also at 15 days, of duplicate samples of seeds stored dry after maturity for 10, 20 and 30 days prior to being tested. The general amount of dormancy may differ in different seasons as shown for oats in 1947 and 1948 (Tables 3 and 6), and at present there is no way of knowing in advance what the particular effects of a given season on dormancy are likely to be. The tests are well along before this information begins to be available. Therefore, while the abbreviated dormancy tests may be valuable as preliminary elimination tests, they cannot replace the more comprehensive tests. In addition the occurrence of return to dormancy in most of the oat varieties might mean that tests for two years should be considered essential to establish the dormancy rating of an oat variety. Nevertheless, the results on oats obtained in this study show that, despite the recurrence of dormancy, an abbreviated test would have separated satisfactorily short dormancy varieties from long dormancy varieties.

*Varietal Heterogeneity Respecting Dormancy*

The dormancy results in this study, as illustrated by the germination percentages given in Tables 1 and 7, suggest strongly that the varieties of wheat, oats and barley in general farm use are by no means pure breeding with respect to this character. In fact, the data indicate that each variety, with few exceptions, may be a mixture of biotypes. Further work is under way at Saskatoon to check this assumption. Tangible evidence favouring the assumption is the difference in dormancy period between Reliance and Reliance C, a selection with a distinctly longer dormancy than its parent. Other evidence is the wide range in dormancy among 20 lines selected from the unnamed but morphologically uniform variety Comet-Apex 11. Two of the lines, C.A. 11-101 and C.A. 11-19, rank high for length of dormancy whereas other lines have intermediate dormancy and still others rank as low as Reliance, Red Bobs and Rescue (see Tables 2 and 5). It may well be that selection for uniform long dormancy might be worth-while in such varieties as Thatcher and Saunders wheat.

## SUMMARY

1. Dormancy tests were made on 62 spring and 7 winter varieties of wheat, 26 of oats and 40 of barley in 1947 and on 12 varieties of wheat, 8 of barley and 8 of oats in 1948 at Saskatoon, Sask.

2. The main purpose of the tests was to improve on existing testing procedures and to devise if possible a suitable abbreviated preliminary test to use on hybrid lines.

3. The tests were made in cloth-covered beds of moist sand on a basement floor with duplicate samples of seed which had been stored for various lengths of time after maturity. Germination readings were made after 5, 10 and 15 days in most cases.

4. Tests were made on both unthreshed and threshed seeds of 12 varieties of wheat and 13 of oats in 1947, and of 12 varieties of wheat and 8 of oats in 1948. All barley tests were made on threshed seed of hulled varieties.

5. The varieties of each crop showed a wide range in dormany in both years.

6. The results in 1947 agreed well with those of 1948 and there was general agreement between the unthreshed and threshed seed results.

7. Study of the results indicates that an abbreviated test, consisting of germination readings at 4 or 5 days, again at 8 or 10 days, and for some varieties also at 15 days, on seed stored for 10, 20 and 30 days after maturity would be useful as a preliminary test. It is suggested that such a test would clearly separate short and long dormancy varieties in one season, but that to get an accurate ranking of varieties or lines a two years' test would be necessary, especially in oats.

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# NEW AND IMPROVED METHODS OF EXTRACTING FAT FROM CHEESE, FRESH CURD AND MILK FOR FAT ACIDITY DETERMINATION[1]

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A number of methods have been published for extracting fat for the determination of fat-acidity in cheese. Lane and Hammer (1) accomplished this by submitting a mixture of cheese and sand to pressure, separating the fat, and finally filtering it through a dry paper. Irvine (2) greatly simplified the procedure by leaving ground cheese to oil off in tall beakers set in warm water. The melted butter fat was used directly.

For some time a procedure similar to that of Irvine's has been used by the authors (3). It consists of placing a grated Cheddar cheese sample in a suitable funnel provided with a folded filter paper and supported in a 65° C. oven. At the elevated temperature the cheese fat melts, runs down and filters into a small receiving flask. The temperature selected does not appear to be critical and 100° C. has been successfully used, shortening considerably the filtration period.

While this method was found satisfactory for Cheddar cheese, considerable difficulty was experienced in extracting the fat from fresh cheese curd. In working out a method for extracting fat from fresh curd an improved method was also developed for cheese. The new procedure for extracting the fat from young and aged cheese is as follows: Approximately 250 grams of cheese are ground in a Waring Blendor, transferred to a 600 ml. beaker and heated in the dry state on a boiling water bath until "oiling off" occurs. Sufficient fat (20.0 gm.) for duplicate tests may be obtained in less than thirty minutes of heating. The fat is then transferred to a funnel provided with a filter paper and held at 45° C. until sufficient fat is collected.

In separating the fat from fresh curd, it has been found necessary to further modify existing methods of fat extraction. Approximately 800 grams of curd is taken and divided into portions of a size permitting convenient grinding in a Waring Blendor. Each portion is finely ground in the dry state; then without stopping the blendor, 500 ml. of hot (90° C.) water is added and the whole thoroughly mixed. This process is repeated for each portion. The water-curd mixtures are poured off into beakers and held at 0° C. until a fat layer has been formed. The fat is skimmed off, placed in an Erlenmeyer flask and churned by hand or by a mechanical shaker. The resulting fat is clarified by centrifuging and then filtered.

In order to obtain fat from cheese milk for fat-acidity determination, two quarts of milk at 25° C. are churned in a small Dazey churn until fairly large granules are formed. Sufficient water at 8° C. is added to cool the fat. It is then skimmed off. The fat is then melted, centrifuged and allowed to filter as in the case of fat from cheese or fresh curd.

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Following the isolation of the dry filtered fat, a 10 gm. portion is titrated in boiling 95 per cent neutral ethanol using 8 drops of phenolphthalein indicator. The titration is essentially that which has been deleted from the fifth and sixth editions of Methods of Analysis (A.O.A.C.) (4), but is still useful in certain phases of dairy science. The result is expressed as ml. of N/10 NaOH per 10 gm. fat and is termed the acid degree.

## SUMMARY

New and improved methods of extracting fat from cheese, fresh curd and milk for fat-acidity determination have been described. A simple method for determining the acid degree of cheese fat has also been included.

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